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BULLETIN

of the

American Association of Petroleum Geologists

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BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, CHESTNUT-SMITH BUILDING, TULSA, OKLAHOMA

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THE BULLETIN is published by the Association on the 15th of each month.

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BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is \$15 per year (separate numbers, \$1.50), prepaid to addresses in the United States; outside the United States, \$15.40.

CLAIMS FOR NON-RECEIPT must be sent within 3 months of date of publication, to be filled gratis.

BACK NUMBERS, if available, may be ordered from Headquarters. Price list on request.

	<i>Mem.</i>	<i>Non-Mem.</i>
Cloth-bound Bulletin, Vols. 12 (1928)-15 (1931) incl., each	\$5.00	\$6.00

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 BOX 979, TULSA 1, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

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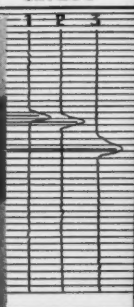
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BULLETIN
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AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

MAY, 1948

APPALACHIAN AND ALPINE STRUCTURES—
A COMPARATIVE STUDY¹

AUGUSTIN E. LOMBARD²
Geneva, Switzerland, and Pittsburgh, Pennsylvania

ABSTRACT

The object of this paper is to compare the complex systems of folds and the structures of two different chains of mountains.

A direct parallelism is not expected, because of the differences in orogenies, evolution, and location. But certain common features may be pointed out which offer new aspects on the origin of the mountain chains in general.

As introduction, a description of the two systems is given, then the comparison is developed, leading to the conclusion that a part of the Piedmont-New England area may be similar to the Alpine geosyncline before it was deformed by the last phases of intense napping at the end of its paroxysm of shortening. Some pre-Alpine nappes may be compared with klippen of the Blue Ridge.

The writer is fully aware of the hypothetical and general character of this paper. He intends, nevertheless, to introduce some new factors in the structural analysis of two major chains of the earth.

APPALACHIAN CHAIN

The Appalachian system extends along the eastern side of the North American continent from Newfoundland to Alabama, a distance of 2,000 miles. It disappears on the northeast into the Atlantic Ocean and on the south is covered by Cretaceous and Tertiary beds of the Gulf of Mexico basin.

The possibility of its connection with the Ouachita Mountains has been suggested. A structural link is possible but hypothetical. W. A. J. M. van Waterschoot van der Gracht (1931) has shown the similarity of evolution of the two chains and considers them as a unit. Hans Stille (1933, p. 834) compares the relations of the Appalachian and Ouachita with the Armorican and Variscan systems in Europe, separated by "eine Scharung," a term which may be best translated as an "angular linkage."

The other limits of the Appalachian are given on the southeast by the Cretaceous cover of the Atlantic coastal plain and by the Atlantic Ocean in New

¹ Read before the Pittsburgh Geological Society, February 14, 1947. Manuscript received, February 9, 1948.

² Chairman of the department of geology, University Libre, Brussels, Belgium.

England and Canada. On the northwestern side, a limit is much more difficult to draw (Keith, 1923).

The gentle folds of the external part of the chain extend far toward the west and reach the Mississippi Valley. They decrease westward in intensity and lose their typical trends. Certain areas are more sharply defined. This is the case in Alabama, West Virginia, Tennessee, Pennsylvania, New York, and Canada and in general along the sectors of the main salients.

The general trend of the chain is southwest and northeast but there are many local changes. The most important of them are large salients, corresponding with maxima of folding, separated by re-entrants. The main salients are in northern Vermont, in southern Pennsylvania, in the western part of North Carolina. The recesses are in northern New Jersey, southern New York, western Tennessee, and central Alabama.

The beds represented in the folds comprise all the sediments from the Cambrian to the upper Pennsylvanian. Large parts of the pre-Cambrian basement seem to be passively involved in the core of the folds (Stose and Jonas, 1933).

Outcrops of pre-Cambrian rocks are very important and form broad areas. They can be grouped under the following categories, according to recent maps (Geol. Soc. America, 1946; Amer. Assoc. Petrol. Geol., 1941):

a. Early pre-Cambrian sedimentary, metamorphic, and crystalline rocks with igneous masses. They were deformed in early pre-Cambrian time and during later Paleozoic orogenies.

b. Late pre-Cambrian quartzose sediments: quartzites, marbles, and schists (Ocoee, Talladega). They are associated with

c. Late pre-Cambrian metamorphics and metasediments: crystalline schists and paragneisses (Glenarm) everywhere deformed by later orogenies and intensely intruded by

d. Pre-Cambrian intrusives: basalts and associated rocks, gabbros, diorites. Also granites and orthogneisses.

The pre-Cambrian age of those formations is hypothetical and is doubted by many geologists. Paleozoic intrusives (granites and basaltic flows, Devonian or Carboniferous) also crop out, and post-Triassic basic intrusions are well developed in the central area of the chain.

The Appalachian system resulted from several orogenies of various intensity and extent: the Algonkian (pre-Cambrian), the Taconic (late Ordovician-early Silurian) mainly in the northern part, the Acadian (late Devonian) also in the northern part, and the Appalachian (late Paleozoic) which is the most important south of New York state.

Minor Ordovician disturbances are locally known, as the Blountian (early Mohawkian), the Vermontian (middle Trenton) and the Oswegan (early Richmond).

In this paper, the study of the structures is limited to the Hercynian-Appalachian part of the chain, from the state of New York, south to Alabama.

Epeirogenic changes occurred in the exterior part of the geosyncline (Allegheny synclinorium) during the whole Paleozoic (Ulrich, 1902, 1911; Schuchert, 1910; G. M. Kay, 1942). Their main structural and active units were: the Nashville dome, the Cincinnati arch, the Algonquin axis for the uplifted regions and the Allegheny synclinorium (including the Rideauan trough), the St. Lawrence basin, and the Champlain trough for the sinking areas.

As stated, the chain considered as a whole is the result of the folding of the Appalachian geosyncline which belongs to a polygeosynclinal type. The structures follow the margin of the Canadian shield and consist of different units: the cratonic geosyncline of the Allegheny (Appalachian revolution), the Champlain miogeosyncline (Acadian disturbance), the Magog eugeosyncline with Acadian intrusives and sinking.

Transverse axes are known north of Lake Ontario at the southern margin of the Laurentian Highlands.

Many major divisions have been proposed in the chain of the Appalachians. It seems possible to reduce them to three: the Allegheny belt, the Blue-Ridge-Champlain belt and the Piedmont-Magog-New England belt.

ALLEGHENY BELT

The sedimentary rocks of the Allegheny belt are Paleozoic in age. The strata rest on the pre-Cambrian crystalline basement. The lithologic series resulted from a slow process of sinking in a broad marine polygeosyncline. Clastics predominate in lower Cambrian during and after the transgression time. They reappear at the regression of the late Paleozoic where the rocks become decreasingly marine and are wholly non-marine above the Conemaugh. Terrigenous sediments mark the main disturbances and accompany stratigraphic breaks and discontinuities. The rest of the thick series consists of carbonaceous deposits. They were formed as the orogenic movements died away. This is the case of the Cambro-Ordovician thick limestones and dolomitic formations and also of the lower Devonian calcareous strata. Many lateral changes of facies occurred during the whole Paleozoic. Clastics increase generally in coarseness and in thickness toward an eastern source of sediments but they have also been provided in terrigenous material from other directions during various periods.

The structure of the Allegheny belt is of two kinds: in the west, broad open folds, well marked anticlines, and synclines; in the east, anticlines and synclines, faulted or thrust, and structures showing a more intense folding with overthrusts, klippen, and nappes. Important windows appear in western North Carolina.

The folds are long and persistent. They show a tendency to pitch and to be replaced by new folds at many places, as in the Jura. Culminations, broad saddles, and replacements tend to interrupt their monotony. As stated, they vary in their directions, forming salients and recesses.

The limit between the eastern and the western groups of folds is called the

Appalachian structural front and has an irregular trend. From south to northeast, it is marked by faults and thrusts in Alabama (Birmingham and Fort Payne), the Pine Mountain overthrust in Kentucky, and the Allegheny front in Pennsylvania. The front disappears farther northeast.

BLUE RIDGE-CHAMPLAIN BELT

The next unit at the east is represented by a crystalline basement of metamorphic rocks with its sedimentary cover and their intrusives. Cloos (1940) includes in this unit (in Pennsylvania) all older crystallines which are unconformably overlain by basal Cambrian quartzites and shales.

The crystallines are mixed injected gneisses: Baltimore gneiss and its associated types of Maryland, Pennsylvania (Mine Ridge and Welsh Mountain gneiss, Blue Ridge gneiss), New Jersey, and New England.

The gneissic rocks generally form domes with typically primary anticlinal shape and also fault blocks that may be modified by local or later structures but remain independent of the Glenarm series of Appalachian trends.

The related intrusives consist of granitoid rocks. They extend to the north as well as to the south Appalachians. They are probably post-tectonic and of various ages, mainly Carboniferous (F. E. Suess); in some places, oblique to the older structures.

The gneisses seem to correspond with the lowest known element of the chain forming its basement. They are probably pre-Cambrian in age.

The sedimentary cover is Cambrian and its transgression truncates the gneissic original structures. Clastics occur locally in North Carolina and in Tennessee; they form klippen and their origin is certainly more internal than the strata on which they lie. Their exact age is not known.

The western limit of the Blue Ridge-Champlain belt is marked by strong tectonic features, like faults and overthrusts. In the south, there is a typical allochthonous mass overriding the former unit.

The thrusts and fault line are made of the following elements, starting from the south: the Cartersville overthrust, the Fries overthrust, the Harpers Ferry overthrust (*pro parte*); and in Pennsylvania the belt passes into the strongly folded rocks of the Paleozoic. It crosses the eastern Adirondack along a north axis and ends in the Champlain-St. Lawrence overthrust.

PIEDMONT-MAGOG-NEW-ENGLAND BELT

This broad and long complex belt extends from New Brunswick and Maine to Alabama. Its eastern limit is unknown. It is at present bounded by the Atlantic Ocean northeast of New York and by the coastal plain deposits farther south.

Its western or exterior limit is, like the limit of the Blue Ridge belt, underlined by a series of overthrusts, klippen, and faults. The most important are, from the northwest to the southeast (A.A.P.G. map): the Champlain-St. Lawrence

overthrust, the Taconic overthrust sheet, the complex and partly hypothetical Martic overthrust, and the Brevard overthrust (North Carolina). Between these big thrusts, there is a line of faults and frontal folds marking a structural border along the entire belt.

According to Ashley (1938, p. 426) the great thrust moved somewhat cross-wise to the original lines of sedimentation suggested by Devonian isopachs but this is no more true for the structural front in Pennsylvania than it is farther south.

Within those limits, the Piedmont belt consists of a folded basement of metamorphic rocks of unknown age consisting mainly of metasediments and crystalline schists grouped under the name of the Glenarm series. They show associated less metamorphosed sediments: marbles, shales, phyllites, quartzites, called the Wissahickon schists in Pennsylvania-Maryland.

The metamorphic rocks are strongly intruded by masses of igneous rocks, as the following. 1. Granites, in batholiths generally more or less deformed, form vast elongate outcrops. In Virginia, granites intrude the Wissahickon schist. They are considered late Paleozoic or possibly earlier in age. 2. Basic intrusions consist mainly of greenstones accompanied by shales and volcanic tuffs (Catoctin metavolcanics). The Piedmont basic rocks may be compared with those east of the Green Mountains in the Taconic allochthonous (Kay, 1941). Cloos (1940) describes an interbedding of greenstones and tuffs with parametamorphics (quartzites, phyllites) of the Glenarm series in Maryland. Jonas and Stose (1939) have observed that the volcanics rest on the granite. This fact would ascribe an older age to the granite that intrudes the southern part of Catoctin uplift. Cloos states that he never considered, in the field, the possibility of granitic intrusives into volcanics.

The sedimentary cover of the Glenarm series is metamorphic, and undetermined in age; it has been formerly supposed to be pre-Cambrian but more recently it was considered as possibly early Paleozoic. This statement is important and deserves further investigation. Cloos (1940) in Pennsylvania considers that all members of the Glenarm series belong to a particular mass of rocks not included in the gneissic basement. The reason is that a part of these members rests mechanically on Baltimore gneiss and nowhere has a basal Cambrian been observed lying unconformably on any of them.

This difference is not only structural but petrological. According to Knopf and Jonas (1929, p. 130): "... it is possible that the Baltimore gneiss remained an inert mass so far as later metamorphosing influences were concerned." The conclusions are generally admitted that the so-called "gneissic basement" is a part of the Blue Ridge-Champlain belt and that the Glenarm series belongs to the next unit: the Piedmont (A.A.P.G. map, 1944). The age of the Glenarm series has been assigned to the pre-Cambrian in numerous recent papers. Some authors consider the Wissahickon formation as a metamorphic facies of the Martinsburg Ordovician shale of the Blue Ridge belt. J. H. Mackin (1935) claims that in south-

eastern Pennsylvania the Glenarm may be wholly or in part Paleozoic, that it is younger than the basal quartzites covering the basal gneissic formation of Baltimore and fills vast synclinoria between the gneiss domes.

These different meanings are of a great importance for the structural pattern of the chain as an "orogen." They lean to two interpretations of the Glenarm series in the frame of this orogen: (1) the Glenarm is pre-Cambrian and it forms a basement complex of wide extent that can be compared with some cratonic unit; (2) the Glenarm is younger than pre-Cambrian and may represent the material metamorphosed and folded in a mobile belt bordering the present chain.

Cloos and Hietanen (1941) consider also the hypothesis of an inner axial belt of metamorphic crystalline and igneous intrusions comparable with the Odenwald, the Black Forest, and other similar Variscan massives of Germany. A part of the Piedmont belt, near its western margin, shows nappe structures that were formed during the main orogeny. They are thrust over the Blue Ridge zone. The rest of the belt is little known. Evidence has been reported of intensely folded formations, including volcanics of generally admitted Paleozoic age, but including also probably older phases of stresses.

Overthrusts, folds, and faults have been mapped in the whole belt and show a general trend following the main axis of the chain. Broad granitic areas, nevertheless, show tendency to extend across the axes of folding.

TRIASSIC DEPOSITS

The paroxysm of Appalachian orogeny was followed by a renewed activity of sedimentation, mainly of terrigenous origin. Triassic clastics were deposited in thick masses along structurally negative areas. They occur in the three main units of the chain, particularly in the Blue Ridge and the Piedmont. They are post-Appalachian in age but Appalachian structure has determined their trend (Cloos, 1940).

Triassic deposits are intruded by late post-orogenic basic flows in many places.

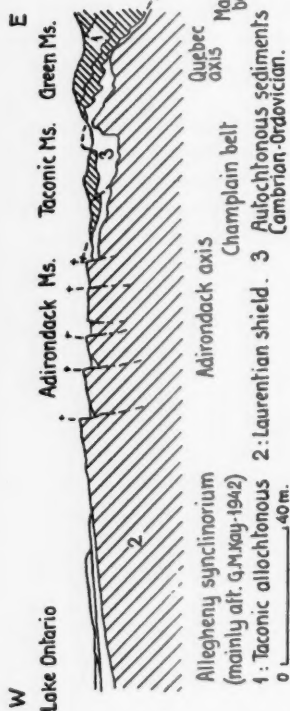
THREE APPALACHIAN PROFILES

I. NORTHERN NEW-YORK PROFILE

From west to east, the following elements are represented.

1. *The Allegheny synclinorium*, the easternmost part of which is the temporary Rideauan trough. This broad synclinorium is limited by uplifted areas: the Cincinnati arch in the west, the faulted pre-Cambrian hills of Ontario, and the Frontenac axis. In the east are the Adirondack Mountains and their southern equivalents marked by the frontal structural trends of the Blue Ridge belt and the Appalachian thrust sheet.

According to Kay (1942, p. 1603): "... the several limiting uplifts differ in character and times of origin and the synclinorium is complex." He also has shown the continuous process of lithologic changes of the deposits during the



Appalachian structures

4 Northwestern New York

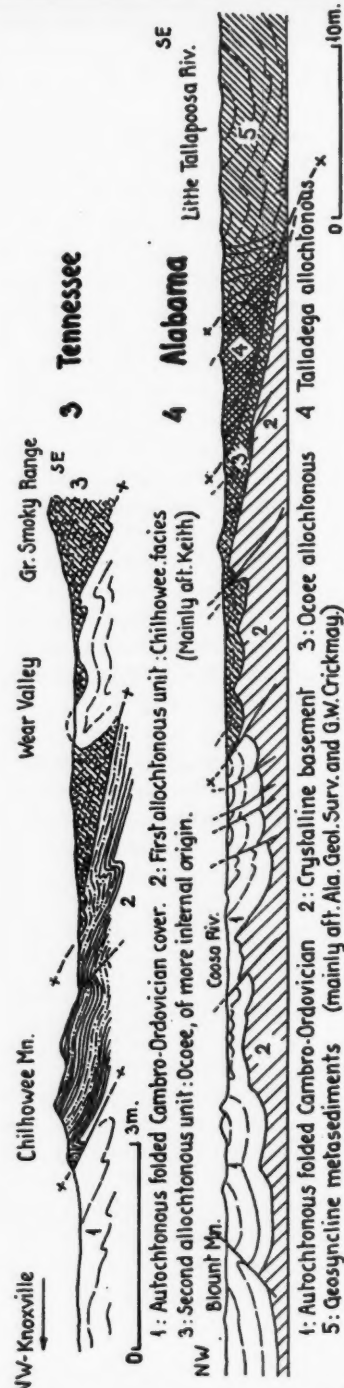
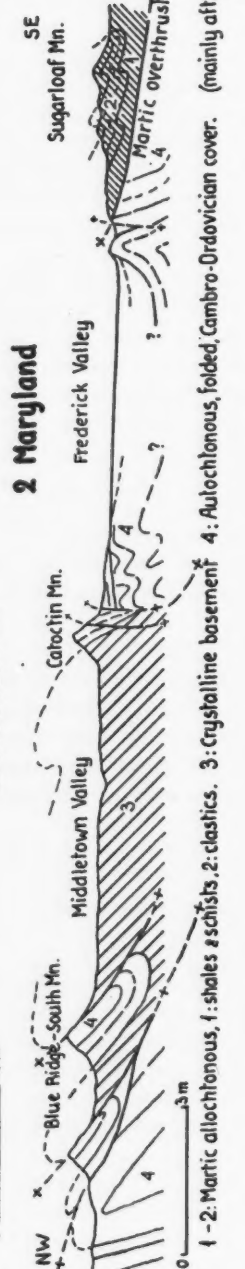


FIG. 2

Paleozoic. There was a gross deformation downward in Early and Middle Paleozoic, followed by slow regression. The great thicknesses of Martinsburg shales and Catskill formations are due to detrital sediments generated by Taconic and Acadian orogenies. Temporary oscillations of the arches and of the bottom of the basins determined the various thicknesses of the big calcareous complexes like the Mohawkian and the Tonoloway-Keyser formations, of the Ordovician and the Silurian (Kay, p. 1627).

2. *The Adirondack axis* appeared first in the middle Ordovician and formed an arch. Later it was transformed by uplift into a dome. Then later faulting occurred and shaped it into block structure (probably in early Silurian).

It is considered as the limit of the Allegheny belt and the Blue Ridge-Champlain belt and may be followed very far southward.

The Champlain belt is the next depressed unit on the east. It was a miogeosyncline of extracratonic character (Stille, 1941, p. 15, quoted by Kay, 1942) until late Ordovician (Cincinnatian) and continued to subside more than its foreland. It has been filled with terrigenous sediments, particularly thick in late Ordovician. Its eastern margin is concealed by the Taconic klippe. Farther north, it shows evidence of a flexure with landslide features (Bailey, Collet, Field, 1928). Kay questions the existence of a Silurian highland along the axis. The exotic blocks of the landslide may be of an erosional origin controlled by uplifts.

3. *The Quebec axis* is now buried under the Connecticut Valley. This positive unit is admitted to have separated the Champlain belt from the Magog trough. It is overthrust by the allochthonous "sheets" of the Taconic clastics related to the Taconic orogeny.

The Quebec axis represents the limit of the Blue Ridge-Champlain belt on one side and the Magog-Martic-Piedmont belt on the other.

4. *The Magog trough* forms the last sedimentary unit on the front of the New England crystalline belt. It is an eugeosyncline (Stille, 1941, p. 15, quoted by Kay, 1942) strongly deformed and the content of which has been thrust over the Quebec axis and the Champlain belt during the Taconic orogeny. The age of the thrusting is probably pre-Silurian and certainly pre-late Silurian. It forms the present allochthonous Taconic Mountains. Its sediments are argillaceous, of fine-grained clastic facies, containing also graptolitic shales, cherts, and volcanics. Exotic blocks have been reported as coming from the Quebec axis. The age of the complex is Cambrian.

Similar klippen of taconic type are known in Newfoundland (Johnson, 1940) and in eastern Pennsylvania near Harrisburg (Kay, 1941).

The source of sediments forming the Martic-Taconic series was in embryonic ranges that were probably located east of the present Blue Ridge (Bucher 1933, p. 132). The northern equivalent of these emerged islands was an undefined and hypothetical land of Vermontia, developed east of the Magog geosyncline within the Appalachian belts (Kay, 1942, p. 1620).

East of the trough is the metamorphic complex of the Piedmont-New England areas with igneous intrusives and magmas.

II. SOUTHERN PENNSYLVANIA-MARYLAND PROFILE

The three main subdivisions are easily recognizable in this section.

1. *The Allegheny belt* has the following features. From the Ohio River to the Allegheny front, anticlines and synclines show exposures as far deep as the Devonian. Mississippian and Pennsylvanian of the coal fields are gently folded. The Chestnut Ridge and the Laurel Hill anticlines culminate in the west. At the east of the folds involving Cambrian to Devonian beds of Bedford County, a synclinorium of Carboniferous and Devonian (Broadtop coal field) is blocked between two thrust faults. East of this, Cambrian to Silurian strata are strongly folded. They extend as far as the zone of the basaltic intrusives and reach the Triassic border fault east of the Gettysburg plain.

2. *The Blue Ridge-Champlain belt* is hardly visible. The whole area of Gettysburg is invaded by Triassic clastics, concealing the crystalline basement and its Paleozoic cover.

But south of the Pennsylvania-Maryland border, there are the well described gneissic domes of the Baltimore gneiss and of the Mine Ridge anticline (Stose and Jonas, 1935-1940; Jonas, 1929; Cloos and Hietanen, 1941).

The anticlines are made of orthogneiss and sedimentary (pre-Cambrian ?) schists. The synclines are marked by outcrops of lower Cambrian and Ordovician quartzites and limestones.

The Catoctin and South Mountain-Ridge anticlines are well developed in the morphology east of the Potomac. They show a core of volcanics flanked or partly covered by Cambrian Loudon and Weaverton clastic formations. The volcanics consist of greenstones, purple slates, and tuffs.

3. *The Piedmont belt*, also called the Martic block, is wide and shows strongly folded formations. The Peach Bottom syncline is one of its folds. It has infolded slates of unknown age and is one of the well developed units.

The Martic overthrust fault appears clearly in Lancaster County, Pennsylvania, on the border of the Mine Ridge anticline. Its presence farther south has been denied by Mackin (1935) but recognized at many localities in the north by Kay (1940). Ernst Cloos (1940) points out that south of the Mine Ridge anticline the overthrust is well within the gneiss area.

The Piedmont area has, besides the crystalline schists, thick shales and slates represented not only in the Peach Bottom region (Pennsylvania) but also in Maryland (Arvonis slate) and near Washington (Quantico slate). They have yielded Ordovician fossils near Washington. Their relation to the Wissahickon formation is given in Virginia where they unconformably overlie granite gneiss intruding the Wissahickon schist (Kay, 1940).

III. CENTRAL AND SOUTHERN APPALACHIAN PROFILE

This section passes across the region of North Carolina that has been recorded in the folios of the United States Geologic Atlas, as surveyed by Arthur Keith.

H. Boesch (1936), based on previous works, has given a general description of

the region and has attempted to compare Appalachian structures with the Alpine type of tectonics. His general scheme is adopted here and further developed.

The main units from west to east are physiographic as well as structural.

1. *Interior Low Plateau and Cumberland-Allegheny Plateau*.—They consist mainly of upper Paleozoic strata, little folded or tabular in the west. They are definitely more folded toward the east. A zone of faults (Kentucky River fault zone) crosses the Cincinnati arch; these faults are on the same axis of pressure as the Pine Mountain overthrust.

Folds are more closely pressed between the Appalachian chain and the Nashville dome in the south showing an increased disturbance at the rear of this obstacle.

2. *The Ridge and Valley zone* is also called the Appalachian Valley zone. It belongs to the Allegheny belt and it is autochthonous. The facies of the series are similar to those known in the east, showing a marine epicontinental character which is lithologically controlled by the main epeirogenic and orogenic phases.

Structure is due to the Appalachian late Paleozoic orogeny. It shows elongate and persistent anticlines and synclines faulted or broken in many places by fault thrusts (U. S. Folio 151, 16). Big overthrusts involve thick and massive series of sedimentary rocks. The most important is the Cumberland overthrust block. Charles Butts (1940, Pl. 60) gives a section showing the thrust mass of upper Ordovician onto Pennsylvanian, lying on series from Ordovician to Carboniferous and cut by the Pine Mountain overthrust with the Fourmile Creek window. The length of the overthrust can be estimated at a minimum of 30 miles. It is not the only one. Others may be mentioned as the Holston Mountain (Tennessee) thrust klippe, the Cherokee Mountain klippe, south of Johnson City, Tennessee, of a more internal origin, the Pulaski overthrust with its corresponding windows near Roanoke, Virginia, and the smaller ones farther northeast along the Shenandoah valley. Trends are subjected to changes according to differential pressures between obstacles in the foreland and wide overthrusts in the Blue Ridge unit.

3. *Blue Ridge zone*.—Structurally, the Blue Ridge zone is marked by important overthrusts: Cartersville overthrust, Fries overthrust, *et cetera*. Lithologically, it underlines a change from the epicontinental series of the foreland to more clastic units of a smooth flysch character deposited in orogenic troughs and basins. A part of them is epimetamorphosed. Fossils are rare or absent and their ages are uncertain. Hypothetical stratigraphic characteristics have been based on lithologic similarities. These strata have been called the Great Smoky series (Boesch, 1936, p. 266) and their basement is mainly granitic (Cranberry granite) or gneissic.

According to Arthur Keith (Knoxville folio, structure sections DD), the Cambro-Carboniferous of the autochthonous series is covered by the thrust mass of the clastic Cambrian members of the Chilhowee Mountain; the latter forms a tectonic unit which is separated by a new fault from the next eastern thrust of faulted masses. These masses are the Knox dolomite and the clastics of unknown age named the Ocoee group.

The Chilhowee is a first exterior allochthonous unit of the Blue Ridge zone thrust over the Ridge and Valley zone. It is overridden by the Ocoee group of a more internal origin. A thrust plane may be assumed between the Knox dolomite of the Chilhowee unit and the Ocoee group, for those two series are certainly not in a normal sequence as Boesch described it (1936, Fig. 1). The age of the Ocoee is still unknown and is supposed to be early Paleozoic or older. But this complex could also be a comprehensive series including a part of the whole of the Paleozoic under a detrital facies. This of course implies a considerable change in the structural explanations of this section, but must be considered in further attempts to correlate the different thrust-faulted blocks belonging to this area.

The next constituents of the section toward the southeast are to be found on the Nantahala Quadrangle, farther south. According to section *CC'* of the Nantahala folio, the coarse clastic formations corresponding with the Ocoee are intensely folded and thrust. There is no thrust plane given by Keith between them and the pre-Cambrian gneissic area which is considered as belonging to the Piedmont belt. But the presence of such a plane seems more than a mere hypothesis.

The granite of the basement appears in wedges among the gneissic units at the southwest end of the area, so that the Piedmont crystalline is in direct contact with the Ocoee series.

Farther northeast, in the Roan Mountain and Cranberry quadrangles, the relations of the three units are intensely disturbed and opinions vary considerably about attributing certain crystalline formations to the Piedmont or to the Blue Ridge units in the area of Mt. Mitchell and Grandfather Mountain.

This Grandfather Mountain mass of sediments seems to correspond with a culmination and forms a window. The detrital series are injected by basic igneous rocks and show certain similarities of facies with the Catoclin Mountain formations. Their tectonic correlations are, however, very uncertain. Granite seems to be overthrust upon them. It is still impossible to know until further field work is done, whether this granite is a large slice of the Blue Ridge basement or if it is connected with the frontal Roan-Carolina gneiss of Piedmont origin.

The zone of Unicoi intrusions may be considered as a weaker part of the basement, marking the limit between foreland and geosyncline. It is overthrust by gneissic nappes showing similar features as in Maryland.

4. *Piedmont*.—The Piedmont belt extends in width southeastward with broad Paleozoic granitic intrusive bodies and many lines of major diastrophism. It has been folded during many phases and the last, the Appalachian, deformed material already compressed and stiffened. Sediments associated with the gneiss show a strong metamorphism (marbles, shales, phyllites, quartzites). (Geologic map of Maryland, 1933, Alabama, Gaffney-King Mountain folios). Intrusives of basic type are always associated with shales and emphasize the geosynclinal character of the area, as pointed out by Boesch (1936, p. 278).

In Alabama (Adams, 1926), there is a similar profile although structural lines

can not be sharply parallelized. The Blue Ridge belt is strongly faulted and thrust. A klippe appears in the Coosa River region formed by lower Cambrian formations thrust over Ordovician Chickamauga limestone. Smaller klippe of the Talladega slate belong to a more interior and more metamorphosed basin, that precedes the Ashland mica schist and its accompanying intrusives. These facies already belong to the belt of metasediments related to the Piedmont area.

The crystalline basement of the Blue Ridge seems to be buried under their mass which is still more important toward the southeast. The Wedowee schists and phyllites, as well as the Talladega series, have properties of lustrous schists of strongly metamorphic character, preceding the large belt of "igneous schists and gneisses" and crystalline schists that extends toward the coast.

A few wedges of granite recall the granitic slices known in the Grandfather Mountain region. They have been attributed to parts of the basement thrust up and forward by the folded masses of frontal Piedmont.

ALPINE CHAIN IN WESTERN ALPS

INTRODUCTION

A survey of the Western Alps needs an introduction of historical character to show how the ideas have evolved since the early days of their first geological exploration.

In the beginning of the 19th century, L. von Buch, E. de Beaumont, and B. Studer considered the Alps as resulting from the upheaval of the earth's crust under the influence of deep-seated magmatic ascents.

Later, A. Escher von der Linth, A. Baltzer (1870), and A. Heim discovered the allochthonous character of the sedimentary formations. Already in 1770, H. B. de Saussure had pointed out the influence of lateral pressure upon the folding. But it was under the impulse of Ed. Suess (1875), Marcel Bertrand (1884), H. Schardt (1893), M. Lugeon (1902), P. Termier (1903), and finally E. Argand (1911) and R. Staub (1924) that the great milestones of the nappes theory were successively settled. This concept has been the standard scheme for present-day Alpine geology.

STRUCTURE OF WESTERN ALPS

As a whole, the chain of the Alps shows a trend which is parallel with the equator. Nevertheless, the sector considered more particularly here makes a large bend. This local change is apparently due first to the presence of the two Hercynian crystalline obstacles: the French Central massive in the west and the Vosges-Black Forest in the north, then, according to Argand, to the form of the African promontory. A similar bend is known farther east: the Carpathian arc.

The accentuated stress against these old rigid masses has not only determined the arc of the Western Alps but has also caused many other tectonic features of great importance: the virgation of the Jura, the culmination of the Pennine elements, and the overthrust of the pre-Alpine nappes. The plastic structure of the

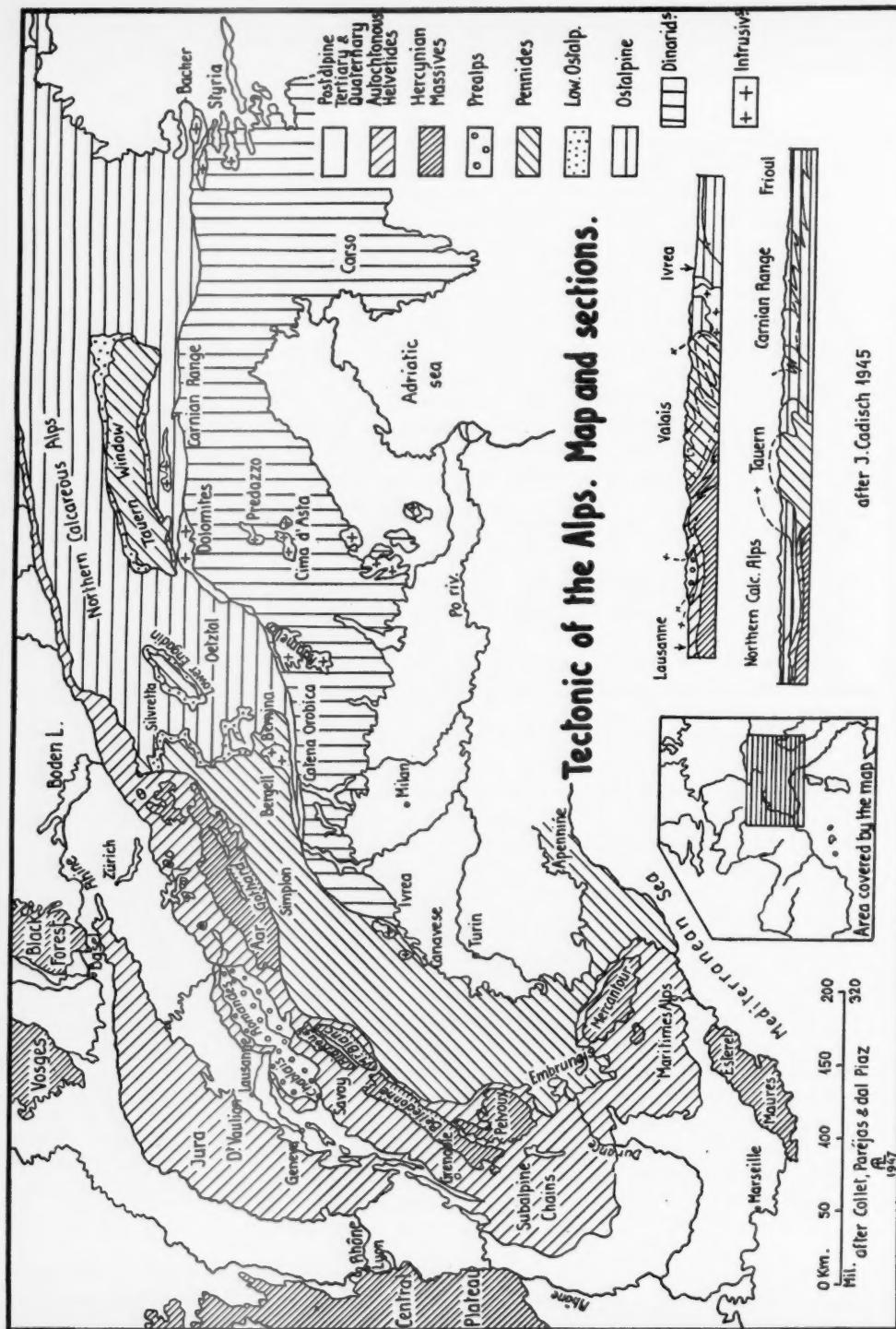


FIG. 3

nappes and the folding of the cover of the foreland reach here their maximum of intensity.

From the exterior of the arc to the interior, the following main units have been identified.

1. *The Jura* is a virgation or a bundle of folds forming a diverging system. It leaves the main Alpine chain near Chambéry in Savoy and ends not far from Basle. Its origin is connected with the Alpine paroxysms of folding. It is the result of two main phases, the most important of them having originated during the Pliocene.

The lithologic stratigraphic sequence of the Jura is epicontinental in type, connected with the series of the border of the Paris basin and with the margin of the Alpine sedimentary autochthonous formations. The core of the anticlines nowhere shows beds older than the middle Triassic (anhydrite and gypsum formations). It has led A. Buxtorf to the belief that the chain has been folded over the middle Triassic strata, the gypsum acting as a lubricating layer. There is a general "plane of detachment"³ which is the post-Hercynian and peneplaned surface of the foreland.

2. *The syncline of the molasse* is the next unit between the Jura and the main chain of the Alps. It is a long trough, extending as a foredeep from the French valley of the Rhone to Vienna. It has been filled by the Oligo-Miocene clastics due to the erosion of the rising Alpine cordilleras.

The vertical sequence shows two marine and two fresh-water episodes and the facies decreases in coarseness from the Alpine margin toward the Jura. Several huge alluvial deltas mark the former mouth of contemporaneous streams that have been considered by Staub as the predecessors of the present Rhone, Aar, Reuss, *et cetera*.

The molasse complex changes in structure from the exterior (southwest) to the interior (northeast). It is folded along the Jura, tabular in the median region and faulted or overthrust along the Alpine margin.

3. *The autochthonous foreland*, in the restricted sense, extends from Nice to High Savoy. It is a folded region but without main overthrusts or true nappe structure. The first nappe appears not far from Annecy where a syncline belonging to the autochthonous passes into a thrust plane. It may be observed in Mt. Charvin. It is the beginning of the nappe of Morcles. Farther northeast, this first nappe is the lowest of a huge structure which develops more elements that are grouped under the name of the Helvetic nappes or the High Calcareous Alps nappes.

The stratigraphic sequence of the autochthonous has the same epicontinental type of facies as the Jura with some slow lateral changes within the Upper Jurassic (Malm) and the Middle Cretaceous (Urgonian). The most important variation of facies occurs in the Upper Cretaceous and particularly in the Tertiary. The Oligo-Miocene clastics of the molasse disappear and are replaced

³ Plane of "décollement" (Collet, 1935).

as orogenic clastics by the Eocene shales, sandstones, and limestones (Nummulitique) of a fine-graded flysch facies.

4. *The High Calcareous Alps* (Helvetides) are particularly well developed in Switzerland, forming long overthrust nappes with typical folds, thrust faults, and recumbent folds magnificently exposed in the Rhone and Linth valleys. Their front is concealed by pre-Alpine nappes in western Switzerland and is thrust over the molasse complex farther northeast.

The roots of the lower nappe (Morcles-Doldenhorn) are pinched in deep-wedged synclines to be seen in the Chamonix and Lötschental valleys, and the Upper Helvetic units (Diableret-Wildhorn) are implanted farther back between the rear of the crystalline central massives at the front of the Pennine nappes.

The stratigraphic Helvetic sequence is still connected with the preceding units. Middle and Upper Cretaceous thicken southeastward and the flysch is coarser in the upper nappe (Wildflysch) with coarse, so-called exotic, blocks.

The ultra-Helvetic nappes lie on top and in front of the High Calcareous nappes. They have been overthrust with the pre-Alpine nappes. They show deeper facies than the Helvetides during the Mesozoic and their flysch is no longer Eocene but begins earlier, in the Paleocene. It has a coarse character also with exotic blocks and Wildflysch at some places (Berra).

5. *The pre-Alpine nappes* are a complex group of many tectonic units, reduced to klippen, the roots of which are not well defined. The first klippen appear in High Savoy, then expand in western Switzerland where they show a larger extent. They disappear in central Switzerland.

Each nappe has its own stratigraphic and lithologic character. The Median pre-Alps nappe shows Helvetic affinities. The Brèche, Simme, and Niesen nappes have a few members still connected with the foreland sedimentary cover. But they are more or less invaded by clastic components. The most detrital series is to be found in the Simme and Niesen units. The latter is considered as entirely invaded by clastics (Niesen flysch) from the Lias to the Tertiary. The front of their bulk lies on the molasse border in western Switzerland. In High Savoy and in central Switzerland they lie on the Tertiary sequence of the autochthonous or even on the flysch of Helvetic units.

The Central massives appear as isolated masses along the arc of the western Alps, from the Mediterranean region to eastern Switzerland. Like milestones, they mark the rim of the foreland, a rim which was first folded during the Variscan revolution and a second time during the Alpine revolution. Their structure shows common features: a granitic batholith, which intruded crystalline schists, a structure of wedges and broken steep synclines with their Paleozoic and Mesozoic highly folded and metamorphosed contents still partly preserved.

Their original sedimentary cover is partly the autochthonous sequence and partly the Helvetic complex. It is poorly preserved. A famous remnant appearing as an outlier is known at the Belvédère des Aiguilles Rouges near Chamonix (France). The rest of the cover has been eroded or displaced by tectonic effects.

The *Pennine nappes* belong to another very different realm: the Alpine geosyncline. The material is metamorphic and its style of folding is quite different from what has been seen on the foreland. A nappe of the Pennine zone may be a true recumbent anticline or a thrust nappe without reversed limb. It has a crystalline core and a sedimentary cover of less metamorphosed rocks, called the Lustrous schists. In the frontal part of the Lustrous schists, some ammonites have been described, belonging to the Lias. Carboniferous and Triassic facies are well developed.

The front of the Pennines lies as an upright mass of folds on the back of the crystalline Central massives, or leaning against the Helvetic or pre-Alpine (?) roots. At their rear part the nappes still have roots which pitch vertically or are even overturned. Basic magmas have intruded the Lustrous schists and have followed the main thrust planes between the major tectonic units.

Although continuous through long distances, the Pennine nappes show axial saddles and culminations. Transverse folding is very sharp in the Gotthard-Leventina region in central Switzerland. This is rather difficult to explain if one tries to correlate the Pennine units from one side to the other of its trends. Staub (1937) has reconsidered the whole problem, giving the equivalents of the Graubünden and Valais nappes.

In Graubünden, the Pennine nappes show a marked pitching toward the northeast so that they disappear one by one under higher elements in Engadin. Finally, the uppermost unit is in its turn covered by the lowest element of the next big tectonic entity: the Eastern Alps. As expressed by G. dal Piaz (p. 483): "le coltre penniniche s'immergono, come in una galleria, sotto all'immensa volta formata dai ricoprimenti austro-alpini . . ." (Austrides or Austro-Alpine nappes).

The Pennines reappear locally farther east in the window of the Lower Engadin and finally in the Tauern.

EASTERN ALPS

The *Eastern Alps nappes* belong to the rear part of the Alpine geosyncline and partly also to the hinterland. They consist of big units with a crystalline core and a sedimentary cover. The latter does not show any longer the facies of Lustrous schists but is less metamorphosed. It is commonly deformed and torn off to an extreme degree. Certain parts of the sedimentary cover of a nucleus have been dragged and laminated along a great distance by an upper overthrust nappe. This is the case of the zone of Fex.

The Eastern Alps cover a broad area of mainly calcareous formations in southern Germany, Austria, northern Italy, and Yugoslavia. Their main subdivisions, from the front to the rear are: the Northern Calcareous Alps, the Eastern Alpine nappes, and the Southern Alps connected with the autochthonous cover of the hinterland, the Dinarides.

The roots of the Pennines and of the lower Eastern Alps nappes are locally injected and intruded by Tertiary igneous rocks of acid type (Bergell granite).

FRENCH ALPS

The French Alps show structural units that may be compared with those described in Switzerland. From the exterior of the chain in the west to the east and toward the interior of the Alps, the following units are crossed.

1. *The autochthonous folds* of the sedimentary cover of the foreland. They pass into the "Sub-Alpine zone" which is still autochthonous and shows a stratigraphy which is tightly connected with the autochthonous and Helvetic sequence of the north. It is called the "faciès dauphinois," equivalent to the Helvetic facies.

2. *The crystalline Hercynian massives*.—They are the equivalents of the Swiss Aar and Gothard units and include: the Mont-Blanc-Aiguilles Rouges, Belledonne, Rocheray, Grandes Rousses, Pelvoux, and Mercantour.

3. East of the crystalline massives occurs the long, continuous overthrust marking the limit between the interior allochthonous and the exterior autochthonous zones. It is called the "*Frontal Pennic overthrust*." Its outcrop line is irregular. The overthrust plane lies nearly flat in the south and shows in a horizontal projection a great double lobe corresponding with the extensive nappe de l'Embrunais-Ubaye of sedimentary formations, mainly of Tertiary and Cretaceous flysch.

4. Farther east, Mesozoic formations reappear, overthrust and strongly folded. They belong to the *Mesozoic zone of the Briançonnais*, which is in other words the Mesozoic sedimentary cover of the main Pennine nappe. Farther north, near Briançon, the series includes Carboniferous.

5. Finally, near the Italian border, *Lustrous schists* cover vast areas, representing the metamorphosed Jurassic and Cretaceous cover of the "Grand nappe briançonnaise" which is Pennic.

Ophiolites and greenstones intrude the Lustrous schists on a large scale.

On the Italian side of the Alps and as far down as the plain of Piémont, the Lustrous schists form extended massives. The gneissic mountains of Val Savaranche, Paradiso, Ambin, and Dora Maira are the equivalents of superior Pennine units encountered in Switzerland.

EVOLUTION OF THE CHAIN

Cadisch (1942, p. 53, and 1946, p. 5) has recently given a clear picture of the different stages of the long history of the Alpine system. So did E. Gagnebin (1942) and R. Staub (1944). They emphasize the following outlines of the structural history of the Alps.

Trends of *pre-Cambrian* structures cross Alpine directions of folding in Steiermark and in Kärnten. Folded metamorphic beds older than the non-metamorphic Paleozoic are known in the Tauern and may be Archean. This is also the case in the gneisses of the Aar and Gothard massives.

The *Caledonian* folding period could not be traced unless the transgression of the upper Devonian (Clymenia limestone) ascertained in the Eastern Alps may be interpreted as its recurrence.

Hercynian folding (Variscan orogeny) is ascertainable throughout with two

phases in the Swiss Alps, one pre-Upper Carboniferous and another in the Permian (pre-Triassic). The granites of the Aar and Gothard massives and of the Err-Bernina nappe have intruded the old structure before the Carboniferous phases. The Pennine region was spared by folding and intrusions (Staub, 1944, p. 3) keeping its original character of possible pre-Cambrian type.

The *Alpine orogeny* probably began during the Lias; it shows orogenic paroxysms during the Upper Cretaceous and in the end during the Tertiary. In the Eastern Alps, the Gosau clastic beds of Upper Cretaceous age overlap nappes which probably originated during Middle Cretaceous time. Later, the mountains were thrust over their own Tertiary erosional products (Cadisch, p. 5). In the Jura, there were older movements during the Eocene and the Oligocene but the main folding is Pliocene in age.

The Alpine Upper Cretaceous orogeny shows the overthrusting of the folds, the raising of anticlinal cordilleras above the sea-level, and the formation of local basins filled with flysch material that spread farther and farther toward the exterior of the chain.

In middle and late Tertiary, deposits of the deltas occur in the molasse trough. During that same time, Pennic material was metamorphosed and intrusives of mostly acid type invaded the roots and their vicinity. The Central massives raised and lost their sedimentary cap. In the Quaternary, before and during the glaciations, the last overthrusts over the foreland occurred.

Finally, in the late Quaternary, a general uplift caused the chain to rise to more than 6,000 feet and gave it its present shape.

MECHANISM OF ALPINE OROGENY

There are two main ways of considering the Alpine mechanism of folding. The first one attempts to consider the Alps within the frame of the earth's history, that is, as a particular case of a very general problem, wider than the chain's birth itself. And the second way, generally based on detailed and recent field researches, considers the chain as a whole. It is certainly striking to observe that there is still no satisfactory synthesis mastering all the different mountain systems of the earth.

Recently, the structures of the Alps were mainly attributed to the drifting of continents, involving important crustal displacements. And accessorially only, magmatic processes were claimed. But they were more particularly proposed for the Eastern Alps. On the other hand, there were the mechanisms that raised other chains like the Hercynides and the Caledonides, including also the formation of some main oceanic areas. They were and still are mainly considered as resulting from magmatic undercrustal movements. But such processes were never directly extended to the Alps.

In the last ten years, Alpine geologists have been turning more and more to a magmatic concept to explain the dynamic process of Alpine folding. The resulting hypotheses tend to join some recent theories on folding of the earth's crust and

ocean-making, so that there is a definite tendency to consider the Alps as part of a general earth-wide process and no longer as a particular case restricted to the Alpine belt. The concepts of mountain-making are based on convection movements in the undercrust magma. Folding, napping, and overthrusting are not as believed heretofore, the central figure, but they are consequences of a more general process. They are considered as relatively superficial phenomena, affecting mostly the upper layers of the crust and tending to be less developed in their basement. The question is to know where and how the crystalline basement of these shortened upper layers has disappeared during the process of folding. According to recent views, the amount of shortening of the earth's crust is not as large as it was supposed to be.

Albert Heim has estimated that the reduction of the Alps, due to their folding, was $\frac{1}{3}$ to $\frac{1}{2}$; and Cadisch (p. 44) finds after accurate measurements that the shortening is 630 to 150 kilometers or 24 per cent, which is not far from the values given by Heim.

It is now interesting to consider the opinions of some recent authors on the general problem of mountain formations. W. H. Bucher (1940) thinks that the long and large geosynclines originated during phases of tectonic quiescence and the folding of their series occur during diastrophic cycles generally expressed by a regression of the oceans. Von Bubnoff (1942) advocates that, under a crust of nappes, there is a layer of granitization and metamorphism. Still deeper is a zone of magma affected by flow movements. Certain movements directed downward attract parts of the upper layers that are swallowed, creating depressions where rocks are folded and accumulated.

A. Rittmann (1942) explains mountain-building as being the result of thermal convection. Under the oceans, the magmatic temperature is not the same as under the continents. The resulting thermal gradient causes a current toward and under the continent. Subcontinental flows cause stresses in the crust, fissures, and uplift.

O. Ampferer published in 1906 his theory of the "swallowing" of higher crustal units by magmas. More recently (1942) he expressed the "understreaming theory" based on extended field work. According to his hypothesis, the deep magma sinks and flows out. The sinking masses are partly replaced by ascending magmas.

In the case of the Alps, the pre-Alps and the Northern Calcareous Alps would represent an excess material, expelled out of the central shortened zone. The Pennine nappes fill the central area of depression and contraction. The Southern marginal zone with its granitic intrusive masses has been called a "young melting zone."

Ampferer has considered, that from the earlier times, the overthrusting of Helvetic nappes and other similar units were not due to direct tangential push but resulted from sliding along thrust planes that are old erosional surfaces; the sliding of the slabs of strata occurs under their own weight. Nevertheless, sliding by gravity is a secondary phenomenon. The primary one is the movement of the central part of the chain.

As Cadisch (p. 12) and Gagnebin (1945) point out, there is no direct proof of such sliding-by-gravity process and this is a matter of conjecture. But we shall see later that this notion taken as working hypothesis is very useful and could explain a great number of facts observed in the structures of folded units of the Alps belonging to the foreland.

Kraus in 1936 supported Ampferer's understream theory and applied it to the whole Alpine chain. One zone of digestion, the first one, is located in the belt of the Pennines and East Alpine roots; the second is smaller and follows the roots of the Helvetic nappe.

Criticism has arisen against those very schematic views because they disagree with some observed facts (Cornelius, in Cadisch, 1942, p. 47), but as a whole, many Alpine geologists have adopted the principles of Ampferer. The reader may also refer to Bucher's symposium (1933, pp. 211-14) and to the relations that he establishes between the downward expulsion of crustal matter into subcrustal space and the uppermost part of the crust.

Staub (1945) has recently published two more contributions to the Alpine history. The first is the folio "Bernina" of the geological map of Switzerland on the scale of 1:50,000. This beautiful document is the result of 22 years of field researches in a difficult and mountainous country. It shows the pitching of the Pennine nappes under the overthrust mass of the Eastern Alps. It illustrates also the mechanism of tremendous crushing of the Lustrous schists, the reduction of certain sedimentary covers of nappes, and how greenstone sills are inserted between the main nappes. The last have often been dragged and turned into scattered and highly laminated slices. The map has been published by the Swiss Geological Commission.

The second work appeared in the form of a talk delivered at the Swiss Academy of Sciences meeting at Sils in Engadin in 1944. Both papers offer a synthetical view on the formation of mountain chains and of the Alps in particular. Staub states that the mobility of the continents is a necessary basic concept of mountain-making. Continents represent rigid blocks playing an active part in the folding. They are opposed to the passivity of the geosynclines that are mobile and supple belts, an idea which is contrary to Argand's and Haug's classical hypotheses. The folding of the geosynclinal contents is no longer the primary process, but the main factor is its short and nearly ephemeral gross deformation. Primary folding is followed by later pressures exerted by the two continental masses bordering the geosyncline. And these pressures start large overthrusts phenomena in the geosyncline that will increase in intensity till the total folding of the final chain of mountains is reached (Staub, 1944, p. 6).

Sliding and overthrusting are the main processes. The folding is a local consequence, generally to be found only in the front or in the rear of the thrust masses. Another postulate of this process is the thinness of the bottom of the geosyncline, explaining its ability to fold and the common presence of ophiolitic intrusions.

Deformations among the continental masses are of a different type, giving

birth to mountains of a much simpler structure, like the Pyrenees or the Atlas. Breaks may occur that open systems of faults (Red Sea, Rift Valley). Any relief on the earth is due to mountain-making forces and to forces that displace the continents. The mountain-making movements are not limited to narrow mobile belts but are extended to all continental blocks and also to the bottoms of the oceans.

Staub takes the Alps as a basic example to analyze the mechanism of mountain-making. Following Argand's views, he considers the folding as a long tectonic evolution. The main nappes of the Pennic or East Alpine type are the result of first embryonic geanticlines that have been further compressed by lateral efforts within the narrowing geosyncline.

The formation of the main nappes is the ultimate result of a continuous process. An embryonic geanticline arises first and later becomes asymmetrical. A thrust plane is formed at the base of its frontal part, then ophiolitic magma follows the plane, and the overthrust mass progresses on a lubricated bed. The resulting nappe has no reversed limb and belongs to the type of a "nappe cassante" as it has been called by Termier and Schardt.

The part of the deep magmas is important during the whole process. It begins with the formation of the geosyncline due to the melting of the subsurface of the crust at the contact with the subcrustal magmatic mass. A lubrication of the thrust planes soon follows after the shortening has begun. Magmatic process of convection also starts the drift of the continental rafts. The magmatic currents are probably due to convectional streams controlled by the differences of radioactivity, of heat, and of density. The rotation of the earth and the change of the polar axis may also control the complex phenomenon on a broader extent, always destroying the new established equilibrium between the magma and the crust.

There are cycles of activity and of quiescence, the value of which may be estimated to 220 million years for the Alpine cycle (Mesozoic and Tertiary) and to 450 million years for both Paleozoic cycles. The average length of a cycle would be approximately 200 million years.

The Alpine cycle may be separated into phases. The first one occurs during the Permian and the Triassic, corresponding with the formation of the first geosynclinal trough.

During the second phase, which begins during the Rhetian, the two continental masses get narrower and the geosyncline begins to sink and is subdivided into minor units separated by broad geanticlines with their thrust planes and their crystalline cores. The process arrives at an apex during the Upper Cretaceous and the Tertiary.

Staub (*op. cit.*, p. 16) states that the resulting type of mountain chain is a function of the intensity of the reduction of the crust under magmatic fusion. We take this statement as a conclusion that allows us to compare the Alps and the Appalachians.

FOLDING BY GRAVITY AND SLIDING

Before making any attempt to compare the Appalachian and the Alps, a few words must be said on one of the most controversial subjects concerning the mechanism of the making of mountain chains: the folding by gravity and sliding.

The hypothesis is complex, has many interpretations, and was proposed many years ago but forgotten. It can be applied to the general problem of the origin and the evolution of mountain chains as well as on a smaller scale to more local phenomena of folding. This latter point of view prevails in the following paragraphs.

Luigi Bombicci in 1882 considered that the folding of the southern Apennines was the result of a slow process of sliding on an erosional surface. Reyer (1892) also generalized the hypothesis and R. A. Daly gave it a wide scope (1918), then more recently reconsidered it (1938), taking in account the experiments and the observations of Kuenen.

It was seen, in the last chapter, how, for Staub and Holmes, magmatic actions determine a sinking of the geosyncline. Daly, von Bubnoff, Rittmann, Ampferer, and Gagnebin arrive at a generally common notion of the primary rôle of the magmas, followed by the structural repercussions upon the crustal cover.

Continental slabs slide on a large scale toward the depressed center of the geosyncline under their own weight. Gravity is the source of energy that will determine later overthrusts and folds. Daly has called it the "downsliding" or the "landslide hypothesis."

As applied to the particular case of the Alps, the hypothesis of explaining the folding by sliding under the influence of gravity is not a new one.

Different historical surveys of the question have been published by E. Gagnebin (1942), G. dal Piaz (1943), E. Gagnebin (1945), and J. Cadisch (1942). In short, let us recall that H. Schardt (1893) was the promotor of the theory for explaining the position of the pre-Alpine nappes. In a series of publications, he developed his theory: under the influence of horizontal stresses, the main folds of the central part of the chain must have been raised to a high altitude. A part of them has slid along inclined planes and has reached more frontal regions, still moved by their own weight.

Lugeon (1896 and 1902) applied the idea to the "Préalpes Romandes." But under the influence of the big syntheses of H. B. de Saussure, Ed. Suess, E. Argand, R. Staub, N. Lugeon, P. Termier, and Alb. Heim, the Alps were considered as great overthrust nappes mainly due to tangential (horizontal) pressures connected with continental drift. These views were so strong that they completely overshadowed the mechanism of sliding.

As Gagnebin says (1945, p. 2): "The interest of the theory is less in the explanations that it gives than in the new problems that it opens." And in fact, the value of the theory grows more and more, allowing an understanding of structures that were still hard to decipher.

Among the French Alpine geologists, M. Gignoux, L. Moret, and D. Schnee-

gans (1938) have recognized its value and have called it the "tectonique d'écoulement."

In 1934, O. Ampferer wrote a paper on the forms of sliding in the Alps of Glaris (Switzerland), analyzing thoroughly the classical structure of the High Calcareous Alps which is exposed so well along both sides of the Linth Valley.

Gagnebin (1945) has made an analysis of the facts, extending the notion of sliding by gravity from the pre-Alps to the High Calcareous Alps and reconsidering many of the conclusions at which Ampferer had arrived, especially about the chronology of the different phases of folding and sliding. M. Lugeon and E. Gagnebin in 1941 observed how certain slabs of limestones of the *Préalpes Médianes* nappe were curiously pitching into the lower flysch as if they had been dragged and not pushed. Hence, they got the idea of explaining the movement by a force acting more intensely in the front of an overthrust mass than in its rear.

These views were extended by the authors to the Carpathians, the Apennines the Rif, and the Betic chain in southern Spain.

M. Lugeon published (1943) a short and very striking notice in which the mechanism of gravity sliding is used to explain complex folding in the internal pre-Alps. The hypothesis of the diverticulation of pre-Alpine units is the term created by Lugeon. It applies to abnormal piling-up of nappes without apparent relations and could be freely translated as "differential sliding." Normal and primary stratigraphic sequences of certain nappes have been dissociated during their drift because they had various plasticities. After repeated tectonic impulses and strong tilting, they were dissociated into slabs. These slabs of sediments slid at various speeds and may have overpassed one another, giving finally the quite irregular architecture observed in the "Zone des cols" in western Switzerland.

Lugeon (1941) has even tried to apply the sliding hypothesis to the Jura. According to his views, the sliding of the sedimentary cover lying on the old Hercynian peneplain could be due to gravity. The movement would have occurred during the Tortonian, under the pressure exerted by the thick molasse mass.

This view opposes the former hypotheses of Staub who has always considered that the tangential pressures were most probably transmitted through the crystalline basement. The basement was deformed and wedged in larger units separated from each other by faults (1924) or thrust faults.

The writer thinks that the wedging of the basement could also be considered as an hypothesis to explain the scarp of la Côte and the long Valley of la Venoge-l'Orbe, in western Switzerland (Lombard, 1938).

More recently, D. Aubert (1945) gave a detailed section in the western Jura, interpreting the structure of the Dent de Vaulion by a wedging of the basement rather than by sliding on a flat thrust plane. No proof has yet been brought to confirm those hypotheses and they need further investigation. Geophysical research would certainly produce useful data.

The writer has emphasized in a short notice (Lombard, 1940), the rôle of

sliding when applied to klippen. It permits interpretation of their present shape by reducing the rôle of erosion and it gives a better understanding of the morphology of their environment.

Isostatic sinking follows the thrust of the nappes, particularly in their frontal part (1941, p. 76) and could perhaps explain certain peripheral depressions like the eastern part of the Lake of Geneva (Aug. Lombard, 1938).

G. dal Piaz (1943) recognizes the value of the theory and applies it to the Ligurides in the northern Apennine system. The Ligurides are thrust over the Toscanides 50-60 kilometers toward the northeast under their own weight, but the movement is combined with a tangential push.

This short survey of the problems involved by the tectonics of gravity should not give the impression of a revolutionary application of some re-discovered theories. In fact, there is no break with the classical methods of investigation and the interpretation of the field studies. A new impulse has simply been given to the analysis of the structures but it has also aroused much criticism and it must be applied only to limited cases of Alpine orogenics.

To summarize the present status of these notions, a citation of Gagnebin (1945, p. 16) puts everything in its right place (free translation):

The tectonic by sliding and flowing is not opposed to the positive teachings of the creators of orogenic tectonic. In fact, the sliding tectonic is a complement to the classical tectonic. It is applied to a restricted realm: the surplus of matter due to tremendous pressures exerted on the center of the chain. This surplus flowed over the margin of the old geosyncline.

STRUCTURES OF APPALACHIANS AND ALPS

INTRODUCTION

A comparison between Appalachian and Alpine structures can not be attempted unless some reservations are presented. At first, the two mountain systems have to be examined within the frame of the already existing syntheses that try to correlate the epeirogenic phases of Europe and those of North America. This study is limited to the Hercynian part of the Appalachian chain which expands mainly south of New York state (American Hercynides of F. E. Suess, 1933). This author has already given many points of relationship between the flyschs, the general direction of pressure, and the metamorphism.

The parallelisms of intercontinental chains are mainly based on their chronological relationships, then on their structures. The first point of view that is introduced here leads to a comparison of two chains belonging to two distinct orogenies. It implies that the criteria of analysis will remain mainly structural and not chronological.

Further, there is a fundamental difference in the conception of the nature of geosynclines between American and European geologists. For the former, Appalachian folds originate in a geosyncline of intracontinental character, "within a continent," with Laurentia as a nucleus in the west and a borderland in the east. This is opposed to Haug and other European authors who consider that

geosynclines are formed at the margin of a continent, or between continental masses. Stille (1933) has tried to harmonize the different concepts. The foreland, of cratonic nature, may be during long periods under the sea. It keeps, nevertheless, its stable and consolidated structure, which differs from a mobile basement, also buried under oceanic masses and which will later be subject to renewed foldings. Suess follows the hypothesis of a marginal geosyncline. It is located at the limit of a cratonic North American shield and along the border of a mobile basement of very hypothetical extent, but its structural and petrographical characters recall in many cases similar Pennine and partly East-Alpine tectonic units of the Alps.

Stille (p. 831) has shown that in Europe, the Alpine, Hercynian, and Caledonian chains are different phases in a continuous whole. They are phases in a wide process of shortening of the space between the Laurentian-North European continent and Gondwana. Each phase has added a new consolidated part to the pre-existing cratonic nucleus.

According to Stille, to the extent that Alpine and Hercynian structural phases of Europe have a definite relationship and appear as succeeding stages of a earth-wide process, there is no major objection to suppose that northeastern American orogenics are a part of their system.

Nevertheless, there is a difficult problem to solve, concerning the relation and the similarities of structures of both American and European Hercynian chains across the Atlantic floor. In North America, the geosyncline has been deformed along the Canadian shield. The latter acted as a foreland, and there was a very hypothetical land mass, represented by the Atlantic floor, which may have acted as hinterland. A part of it is still visible in the Piedmont belt. But there is the question as whether the present Piedmont is really and entirely to be compared with a hinterland of cratonic structure with old and already stiffened structures or if it is not also a part of a mobile belt of geosynclinal character. If this is a fact, where are the frontal and the back limits of this cratonic rear mass? The unknown constitution of the Atlantic floor presents an undetermined factor which does not seem to exist in Europe. In northern France, southern Belgium and in Germany, the cratonic character of the hinterland can be considered as proved. It is possible to bring a provisory answer to this still enigmatic side of the Appalachian ontogeny.

The chronology of the different periods of folding has been established on both sides of the Atlantic. Both chains show two groups of orogenies. First, the Taconic and the Acadian corresponding with the Caledonian and the Bretonian in Europe, and then, the Arbuckle and the Appalachian phases related to the Asturian and Saalian of Europe. More precise parallelism seems to be highly hypothetical in this particular field.

SEDIMENTARY COVER OF FORELAND

The Canadian shield represents the crystalline basement of the chain and has an autochthonous character. It is covered by a sedimentary sequence of mostly

marine facies in the west showing there a slow process of sinking. From the Cambrian to the Permian the sedimentation is continuous among the large basins of the Allegheny. Toward the east, it shows an increase of breaks and unconformities passing finally into fine clastic facies of a continental type of sedimentation. Among the marine sequences, the major disturbances are marked by the arriving of relatively coarser clastics, but they remain always of a fine-grained texture. Unconformities are local and correspond with the most important revolutions: the Taconic, the Acadian, and the Appalachian.

The lithologic character of the foreland is mostly controlled by epeirogenic processes that occurred in the area of the Allegheny synclorium with occasional fine clastics of more distant orogenies. Orogenic facies of the shaly flysch type are known in the northern synclinal troughs, mostly in the interior of the chain (Magog and Champlain belts). They are related to the Taconic disturbance.

The Acadian clastics do not spread very far out on the foreland. The molasse facies of Mississippian-Pennsylvanian age are produced by the Appalachian orogeny. They are the only ones to have been deposited far away on the foreland of the east and the Mid-Continent. As Bucher (1933) has pointed out, the Appalachian system yields no peripheral trough that could be compared with the peri-Alpine molasse basin. But the sediments of the Carboniferous offlap are strikingly similar to molasse rocks. The facies exposed along the lower banks of the Monongahela River near Pittsburgh resemble the molasse Oligocene deposits of western Switzerland and High Savoy, including the presence of soft coal. There are no coarse strata like the "micropoudingues" or the "Nagelfluh," but the same sandstones, the green, red, and black shales and fresh-water limestones are equally represented. Cyclothems of Pennsylvanian type have not been described but they are present in part although they are rather difficult to identify. The molasse trough was too narrow and the distance was too short between the Alpine border and the barrier of the Jura. Sediments had not sufficient space or time to settle quietly. It is also probable that the sinking of the trough was too abrupt and irregular.

The relationship of sediments is also striking in the argillaceous-calcareous series of older ages.

The outcrops at the Indian Ladder, east of Albany, New York, show the Cincinnati, the upper Silurian and the classical series of the Devonian. They resemble lithologic profiles in the Jura, at the Faucille (Ain), or in the region of Sainte-Croix (Vaud.)

This analogy may be extended, although with many reservations, to the general sequences of both Appalachian and Alpine forelands.

The Appalachian series begin with Cambrian clastics transgressing on the Algonkian basement as the Alpine series begin with the Permian and the Triassic on the Hercynian crystallines. Later, the calcareous deposits succeed the clastics and are well developed in the Upper Cambrian. They show concentration into dolomites during Beekmantown age.

The Taconic disturbance is felt during the Upper Ordovician with predominant-

ing terrigenous formations. But calcareous deposits prevail during the quiet period that follows during the upper Silurian and at the lower Devonian. Subsequently, the lithologic character is more and more marked by the presence of clastics due to the coming Appalachian orogeny. Local movements of less amplitude are registered by stratigraphic breaks, unconformities, disconformities, or changes in facies.

Taking the stratigraphic sequence of the *Nappe de Morcles* as standard for the Alpine foreland, one may observe similar processes.

After the Permian and Triassic clastics, the sedimentation becomes more and more argillaceous, then passes into calcareous rocks with many clayish oscillatory beds but the calcareous tendency grows until it reaches a first maximum during the upper Jurassic and a second one during the middle Cretaceous. The argillaceous recess is at its maximum at the base of the Cretaceous and it probably expresses the late Cimmerian phase of epeirogeny. Similar Appalachian recesses take place between the two maximas of calcareous deposits of Beekmantown and Helderberg-Tonoloway age. It is not only clayish (*Juniata shales*) but coarser (*Tuscarora sandstones* and *Oswego*) and corresponds with phases of the Taconic disturbance.

The Alpine calcareous series are more or less abruptly replaced by clastics in the Tertiary. They are called the *molasse* in the foreland and *flysch* in the Helvetic area.

The series farther toward the geosyncline show earlier and coarser facies of the *flysch*.

Clastics hide partly the original chemical lithologic sequence in the pre-Alpine "*Nappe de la Brèche*." In other more interior nappes, clastics invade and hide them entirely as in the *Simme* and *Niesen* units.

This invasion of clastics toward the interior of the chain is common to both systems of mountains. In the Alps, it begins earlier in the interior units than in the exterior ones, as Leupold has pointed out. The "*Nappe du Niesen*" which is supposed to originate very near the border of the geosyncline has already a Liasic *flysch*.

This comparison must be made with criticism for at least two reasons. The first is the extreme scarcity of fossils in the interior clastic series of the Appalachian Piedmont and of the Blue Ridge units. Their age is still subject to discussion and is considered as Cambro-Ordovician by some geologists and pre-Cambrian by others.

The second is that the pre-Alpine nappes with their *flysch* are piled up in an order which can not be correlated with their original place of deposition. This necessitates a great deal of hypothesis in any attempt to make paleogeographic and palinspastic constructions.

The equivalents of the *flysch* facies are very limited in the Appalachians. They seem to be restricted to the Taconic klippe and to units like the *Chilhowee* and the *Ocoee* series. They are thrust or block-faulted and everywhere alloch-

thonous. A broader extent of their original basins is still possible to conceive but they can not be very extensive. Their extent has never been determined.

The Alpine flysch is a synorogenic formation, quickly changing in coarseness and composition of constituents. It was deposited in moving and temporary basins unlike any that seem to be known in the middle and southern Appalachians where the basins seem to be more continuous and to have a more monotonous lithologic character, lacking coarse clastics like conglomerates or breccias. They belong to a type of shaly and sandy flysch. Pre-Alpine sequences of the Simme or of the Niesen nappes show quick lithologic changes. They are known at present in limited extent that can not be compared with the Chilhowee or the Ocoee elongate outcrops. Their original basins of deposition had probably very different scales of magnitude.

The important Talladega series have deliberately not been considered with these clastic units for they show much more affinities with Lustrous schists of geosynclinal type.

STRUCTURES OF FORELAND

The folded structures of the Appalachians and of the Jura have already been compared and their similarity has been emphasized (Bucher, 1933; Boesch, 1936; Cloos, 1940).

Nevertheless, there are other facts that must be considered in these attempts to compare the two chains.

The first of these facts is that the Jura is a virgation, a bundle of folds that diverges from the main chain of autochthonous trends of the "Châinées subalpines." A molasse trough fills the space between them and the main chain and increases in size toward the northeast. The second is that the Jura has a limited extent along its length. One end is marked by the presence of the French Central massive and the other by the Vosges-Black Forest obstacle. The Jurassic folds could freely expand on the foreland between these two blocks.

There is no similar virgation or no limited expanding of the folds in the Appalachians. Their trends follow the whole general direction of the chain from Alabama to Pennsylvania, making several large salients and ending in northeastern Pennsylvania as a result of an apparent decrease of the intensity of pressure.

The virgation of the Jura coincides with a part of the maximal curve of the Western Alps and also with the area of pre-Alpine klippen and with the largest and deepest sub-Alpine lakes. They are all connected with the maximal stresses of orogenies located along this curved part of the chain. Another factor in comparing structures involves the folding in the sedimentary cover as related to deformations in the crystalline basement. Are they folded together or has the sedimentary cover been folded independently, as it is shown in the Jura? An answer has been given for the Appalachian. Cloos (1940) has studied the shortening of the chain and he definitively involves the basement in the folding. He considers two possible ways of behavior of this basement: if it participates ex-

tensively, the depth reached by deformations is considerable. If the folding remains above the basement, the depth of folding is approximately equal to the depth of the geosyncline. This latter possibility is perhaps similar to some recent hypotheses on local Jurassic structures.

In Switzerland, the Jura in its northeastern part is folded above the crystalline basement and the latter acted rather passively. But in the southwest, there seems to be a change. Some structures observed in the massive of the Dent de Vaulion and in the valley of the Orbe seem to indicate a wedging of the basement. But it is hardly comparable with the large Appalachian structures. A process of folding by gravity has been suggested for the Jura. It could not be taken in account for the Appalachian sequences which are too thick and stiff to react as Jurassic strata do. The more interior eastern parts of the North American chain show intense folding. They are somewhat like parautochthonous folds with short overthrust planes passing into larger figures. The folds become acute, even upright or overturned. Fault blocks are common. But nowhere are the series piled in Helvetic style, recalling the Alpine High Calcareous nappes.

The Valley and Ridge zone can easily be compared with the autochthonous and sub-Alpine parautochthonous of the French Western Alps. The Cumberland Mountain offers a case of particularly large overthrust. It has already been related to pre-Alpine klippen but it also offers structural similarities with the "Nappes de l'Embrunais," with a flat thrust plane, locally folded and with allochthonous sequence showing no reversed limb at its basis. The Cumberland nappe is, nevertheless, more continuous than the Embrunais mass which shows disrupted units sheared by former movements.

Applied to the Appalachian klippen, the sliding by gravity could explain their present position and their shearing off from their roots. It also could explain the fact that no folds are found at the rear part of the klippe and that there is continuity among the internal structure of the klippen. Old surfaces or erosion acting as thrust planes have been described by Russell, Hayes, and B. Willis (erosion thrusts) but some of them have been denied and critically reviewed by Holden (1936).

CRYSTALLINE FORELAND

Toward the east and at the rear of the older Paleozoic strata appears the crystalline basement of the Appalachian chain. In the north, it forms the Adirondack and the Quebec complex. Farther south, it rises in the Blue Ridge and also in some isolated outcrops in southern Pennsylvania, Maryland, and Virginia.

Structures and petrography of this basement show many features that are common to the Central crystalline massives of the Western Alps.

In Maryland, Cloos and Hietanen have shown that its gneissic composition is different from the overlying Glenarm schists. It is strongly folded and so is its sedimentary cover. Similarly, the crystalline schists in the Mont Blanc are intensely folded together with their Carboniferous synclines.

The region of Quarryville (eastern Pennsylvania) shows that the Glenarm series is thrust over the crystalline basement of the Mine Ridge anticline. This feature shows analogy with the structure of the Pennine nappes lying against or over the old Central Hercynian massives. In the Alps the latter acted as obstacles but in this part of the Appalachian region the basement was too low to stop the flow and it has been evidently overthrust.

In the southern and central Appalachians, Keith has shown that certain sections are intensely faulted and overthrust (for instance the granite in the Roan Mountain Quadrangle). These crystalline masses present structures somewhat similar to the wedges of the Jungfrau, the Lotschental, and the Windgälle. They even take a much wider extent in North America.

The eastern margin of the Blue Ridge crystalline mass is very commonly followed by faults and overthrusts, either in the crystalline chain or in the sedimentary cover. They make a continuous zone that strikes along the whole length of the chain. The equivalent Alpine feature is the "Pennic frontal border" of Termier, Argand, and Staub. It is a strongly marked line of overthrusts and faults, of tectonic scales, of roots, and of dynamo-metamorphosed units.

The Blue Ridge zone may thus be considered as the easternmost structural unit of the foreland and as such corresponds with the situation occupied by the Hercynian Central massives of the Western Alps with their sedimentary cover.

GEOSYNCLINE

In the Alps and particularly in Switzerland, the structural limit between the foreland and the geosyncline can easily be followed along the rear of the Central massives. It forms a zone rather than a line, following the upper Helvetic and ultra-Helvetic roots and also the front on the Lustrous schists as well as the Carboniferous non-metamorphosed belt of sediments.

In the French Alps, the limit is also given by the "Pennic frontal border" (Gignoux, Moret, 1938), which is especially well marked north of the Pelvoux massive.

A similar and sharp limit east of the foreland can hardly be found in the Appalachian chain along its whole length. Locally it appears clearly, as in eastern Pennsylvania-Maryland. But farther south, it seems rather to form a broader zone which is marked by major overthrusts, faults, ophiolitic intrusions, and granitic wedges. It is a long and narrow area of major disturbances called the Martic line.

The Martic line appears as a complex structural zone which corresponds with a long and mobile boundary between the geosyncline and the foreland. This explains why there are so many changes in the nature of the Martic line and why at certain places its presence has even been so often doubted. The Martic line can be compared with the Pennic frontal border of the Alps but it has not its intensity of folding and its unity of formations.

This margin of the geosyncline acts as a hinge between the rigid foreland and

the mobile inner belt. It is thus normal to find its material intruded by basic magmas on a great extent, both in the Appalachians and in the Alps.

In the former, the greenstones of the Catocin Mountain may be compared with certain ophiolite flows of the pre-Alpine nappes (Brèche, Simme) and even to larger masses invading the Pennic Lustrous schists at the Petit Saint Bernard and in the Valais.

The material forming the Piedmont shows many analogies with the crystalline schists and gneisses of the Pennine nappes and their parametamorphic constituents. Even the sedimentary cover of shales and quartzites known from Maryland to Alabama can be compared with Lustrous schists or with less metamorphosed rocks of the same group of nappes. The Talladega series of the southern Appalachians has a typical facies of metasediments of Pennic type (Crickmay, 1936).

There is no doubt that in the Alps the Pennine complex belongs to the geosyncline but this has not been determined for the Appalachian Piedmont. The comparison based on the petrographic similarity of the crystalline schists of the Glenarm and the gneisses of Baltimore seems well established in Maryland and in southeastern Pennsylvania. But farther south, the correlation of the Carolina or of the Roan gneiss with one unit or the other has not been made. Even the definition of the Carolina gneiss is not clear at all. The typical criteria of mobility as reflected in the sedimentary series of this geosyncline have not been analyzed and the age of the metasediments is still unknown. This lack of data makes any attempt of further comparisons very uncertain. We have already pointed out when dealing with the Martic line that the shortening of the geosyncline during the Appalachian orogeny has not been as strong as it appears in the Alps and there is no typical thrust front to be compared with the original Pennic frontal border.

As a consequence of this weakness of folding, there is a more progressive passage from the rear of the foreland into the geosynclinal formations and from the geosyncline into the hinterland. The Appalachian geosyncline is less reduced, compared with the Alps and it can be considered as the floor of a former geosynclinal belt that has been folded and overthrust but not highly napped and subsequently uplifted.

As in a geosyncline, the intrusions have played an extended part, showing the presence of a shallow underlying magmatic basement. Metamorphism has been very strong, acting on all original sediments, mostly clastics or shales. The additional injections of ophiolites show clearly the mobile character of this thin and supple belt of the earth's crust.

All the previous facts and the comparison with Alpine tectonics lead to the following working hypothesis.

The Piedmont area seems to belong partly to a narrow geosynclinal belt of mobile character and partly to a cratonic unit having acted as hinterland during the Appalachian orogeny. The Glenarm series belong rather to the geosynclinal part of it.

It is the belief of the writer that the age of the Wissahickon schist and other sediments of the Glenarm series does not play a decisive part in their attribution

to a geosynclinal belt or to a cratonic hinterland. A comparison with the Alps shows that they can be related to the present Pennic complex which was folded during the Alpine orogeny and prior to it, too. It shows a sedimentary cover with members as young as the Jurassic and probably younger. A part of it has escaped to the metamorphism connected with Alpine orogeny. It also contains strata as old as Paleozoic and even older. Staub, in the geological legend of the new Bernina folio ascribes possibly pre-Cambrian age to highly metamorphosed marbles and quartzites of the Margna Nappe (High Pennine nappes). They have been involved in Hercynian and Alpine orogenies and are made of material forming the Alpine mobile belt.

They represent a part of an ancient oceanic floor involved in several older phases of orogenies of which it has kept a record.

The last orogeny has only produced a part of the metamorphism but not the whole and the final reduction of space by a gigantic intercontinental shortening accompanied or followed by a general uplift. In the Piedmont, this last phase of reduction seems to have been much weaker and shows only embryonic types of structures.

HINTERLAND

The Appalachian hinterland is represented by the broad area of crystallines forming the basement of the coastal plain. It is characterized by highly folded gneisses of various types, intruded by granitic magmas. Its Cretaceous and post-Cretaceous tabular sedimentary cover is typical, showing that this rear mass is rigid and has not been submitted to major diastrophism since the last orogenic phase of late Paleozoic age.

Further field investigations will bring more accurate data on the limits between this rear passive mass and the mobile belt of the geosyncline. The latter seems to be much narrower than in the Alpine system.

In the Western Alps, the limit between the hinterland and the geosyncline is marked by the zone of the roots of the Pennine and East-Alpine nappes. According to the views expressed here, such a zone of intensely folded and metamorphosed rocks is hardly to be expected. It could only be represented by a belt of faults and strongly folded metasediments expressing the different reactions of the basement.

CONCLUSIONS

The comparative study of the two chains would be incomplete if, as a matter of conclusions, it did not attempt to consider them in a more general way. They are not only isolated units of the earth's crust but also episodes of a wide process of deformation.

The place of the Alps among the continent-making chains has been recently reconsidered by Staub. A similar study has not been made for the Appalachians, based on modern geophysics and geotectonics.

Such a synthesis needs a considerable amount of new field work and would still remain uncertain for many reasons, one of them being the hypothetical

nature of the Atlantic Ocean. Once more, the problem of its floor is opened to speculative theories.

F. E. Suess (*op. cit.*, p. 819) says that such nappe structures as we find them in the Appalachian crystalline belt with such a crystalline facies as described by Knopf and Jonas can not have been produced by the free gliding of rock masses but must have originated under the action of a heavy pressure-producing block.

It seems on the contrary that the absence of such an active block could explain the moderate tectonic style of the Appalachian chain. The bottom of the Atlantic did not act like an active cratonic hinterland upon the Piedmont but it worked rather incompletely. The sub-Atlantic block postulated by Suess may exist but may be sunk too. It would thus explain its partial rôle in the final orogeny. The tangential pressures transmitted to the foreland were able to create overthrusts and faulting in the Piedmont, wedging and napping in the Blue Ridge and thrusts, faults, and klippen in the Valley and Ridge region. But nowhere are features like a molasse trough, High Calcareous Alps, either an uplift of the crystalline border of the foreland, or even roots of the main overthrust units.

The original basins of interior clastics are still preserved and little deformed. They have never been swept, dragged, or laminated by superior nappes. And there are nowhere the remnants of an overriding superior element to be connected with the Alpine hinterland or to East-Alpine constituents belonging to a rear part of the geosyncline.

The structural facts can be summarized as follows.

The Appalachians are a part of the world-wide Hercynian phase of orogeny. Certain types of structures are similar to Alpine types and their main units also can be compared. They show a westward folding directed toward the Laurentian continent. The Piedmont has divergent folding. It seems thus that the process proposed by Daly, Kuenen, and R. Staub for the formation of the chain may be applied to the Appalachian system too, but it is weaker and the system has asymmetric constituents and shows consequently an asymmetric structure.

Bucher in the delicate and philosophical conclusion of a recent paper has compared the views of the man of science to an arthropod's eye catching different sights of what he can observe. His brain integrates the visions brought by the facets and groups them in a comprehensive picture.

In the present article, Bucher's insect has reflected the audacious figures of the glowing Alps on some facets and the broad ridges of the Appalachians on others. The resulting impression offers for both Alpine and American geologists a fascinating field of thinking. May this comparative study stimulate new researches and open wider fields to further discoveries.

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GEOLOGY OF BENTON FIELD, FRANKLIN COUNTY, ILLINOIS¹

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ABSTRACT

The Benton pool was opened in January, 1941, and developed so rapidly that practically the entire area was drilled by the end of the year. Oil is produced from the Tar Springs sandstone at 2,000-2,100 feet. Accumulation is controlled by a northward-trending anticline with limited closure, but with abrupt gradation of sand to shale at the south, or critical side. Effective sand thickness is as great as 62 feet and the average for the field is 42 feet. Deeper sands have not been tested.

To June 1, 1947, the field had produced 18,656,892 barrels, and for the month produced 2,123 barrels per day. Two hundred forty-two producing wells were completed, of which three have been plugged. The recovery to date has been slightly more than 77,000 barrels per well for each productive well drilled.

Most of the wells have been drilled through abandoned, active, and projected coal mines, and the special methods used are discussed, as well as the history of discovery, reservoir conditions, and sand conditions.

LOCATION

The Benton field is in central Franklin County, Illinois, south of the city of that name. It is approximately 100 miles southeast of St. Louis and on the southwestern flank of the Illinois basin (Fig. 1). State highway 37 passes from north to south along the east side of the productive area.

HISTORY OF DISCOVERY

The presence of abnormal structure in the vicinity of the Benton field was noted as long ago as 1908 by Cady (Fig. 2) who recognized the fact that No. 6 coal in the area was higher than normal. The writer worked in the county in 1931, and also noted the same evidence of folding, but due to scanty data and lack of time did not map the area in detail.

In 1937, time was available; active development of the Illinois basin was in progress, and a detailed study of the coal basin was undertaken. This involved the collection of all available core-hole data and assembling on a uniform scale, and on sea-level datum, the structural data from as many coal mines as possible. Two abandoned mines south of Benton, the Benton No. 1 and Benton No. 2, produced interesting information when the old survey records were finally located. The No. 1 mine was seen to be on an anticlinal axis, the coal dipping strongly east, west, and north from a point near the shaft. South dip was shown in a less degree to the limits of the worked-out area (Fig. 3).³ These data seemed adequate to justify a test, and a block was secured by E. S. Adkins from the royalty owners, the Chicago, Wilmington, and Franklin Coal Company, and arrangements

¹ Read before the Association at St. Louis, January 14, 1948. Manuscript received, February 16, 1948.

² Consulting geologist.

³ See also a map by Cady, Taylor, *et al.*, dated February 1, 1938, and published as *Illinois Geol. Survey Cir. 24*, which gives a detailed picture of the structure of No. 6 coal, closely resembling that of Figure 3.



FIG. 1.—Index map, showing location of Benton field.

made with an oil company to drill a test well in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 25, T. 6 S., R. 2 E.

After the deal was consummated, however, the company decided to have a

seismograph survey made, and as a result of this work, paid a substantial sum for the privilege of moving the location to the NE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 36, T. 6 S., R. 2 E., which the geophysical survey had indicated was more favorable. A dry hole was drilled at this point in October, 1938, and the lease expired. Light showings were reported in the Tar Springs and Benoist sands.

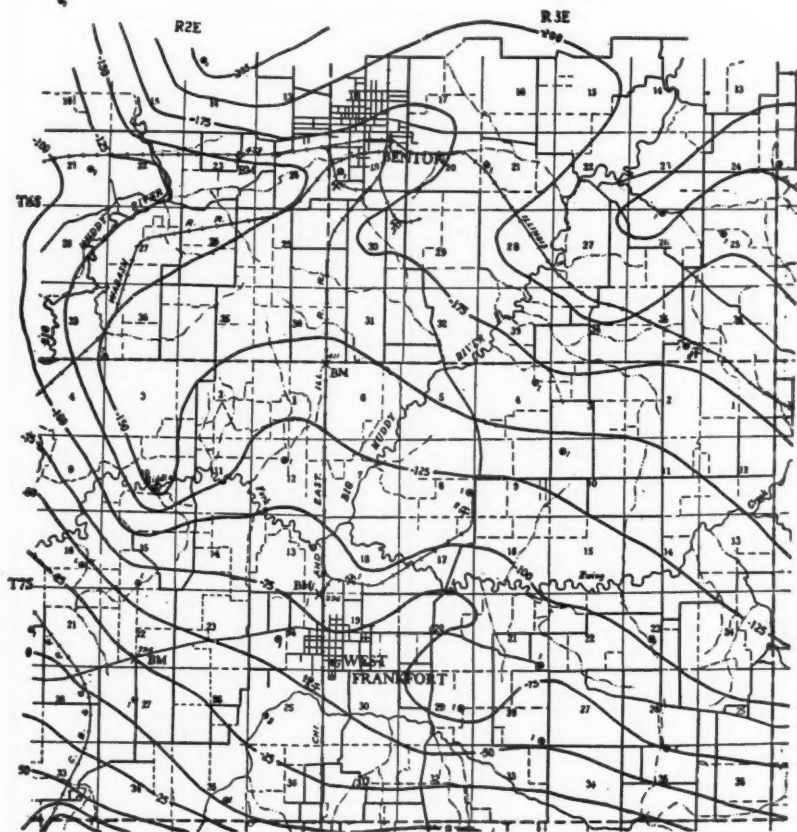


FIG. 2.—Structure map of Benton area by G. H. Cady, 1908. Contours on top of No. 6 coal. (From *Illinois Geol. Survey Bull.* 16, Pl. 24.)

Approximately, a year later, Adkins again secured a lease, much smaller than the original tract, but large enough to include all of the area covered by the known structure. The Shell Oil Company and H. H. Wegener supported this test, the latter's tools being used in drilling. For other than geologic reasons, the location was moved to the NE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 24 and geophysical results were

excluded. After finding 14 feet of oil-saturated sand in the Kinkaid, and 45 feet in the Tar Springs sandstone, the well was completed on January 6, 1941, producing 374 barrels per day from the Tar Springs sandstone.

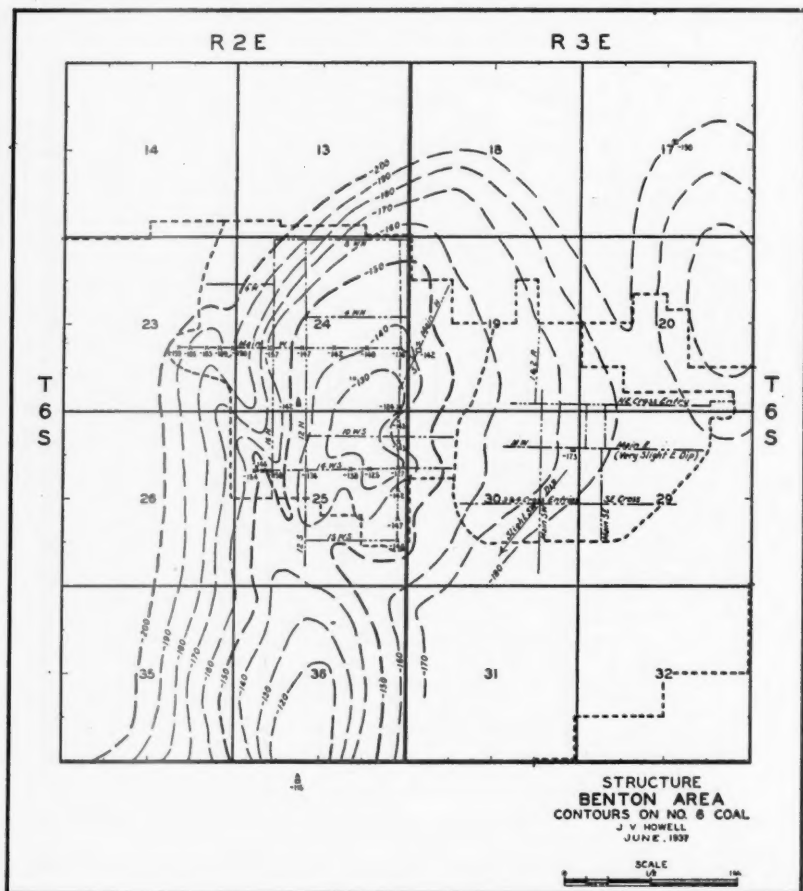


FIG. 3.—Original map of Benton area, by J. V. Howell, June, 1937.

Rapid development ensued, largely because of the habit of operators, other than the foregoing three, of taking leases from surface owners, on the strength of various legal theories whose substance was that warranty deeds dated 1905-1907, conveying coal, oil, gas, and other minerals to the coal company, really conveyed only the coal. After 2 years of litigation, these theories were thoroughly disproved,

but meantime the legal leaseholders were forced to drill every available location, mostly under protection of injunctions and restraining orders. Consequently, the field was delimited and largely drilled by the end of that year. To date, 242 producing wells have been drilled, of which three have been abandoned as non-commercial, and three (on a roadway) were plugged by court order. The remaining 236 wells are still producing.

STRATIGRAPHY

The surface is covered by a veneer of loess and soil overlying shales and thin

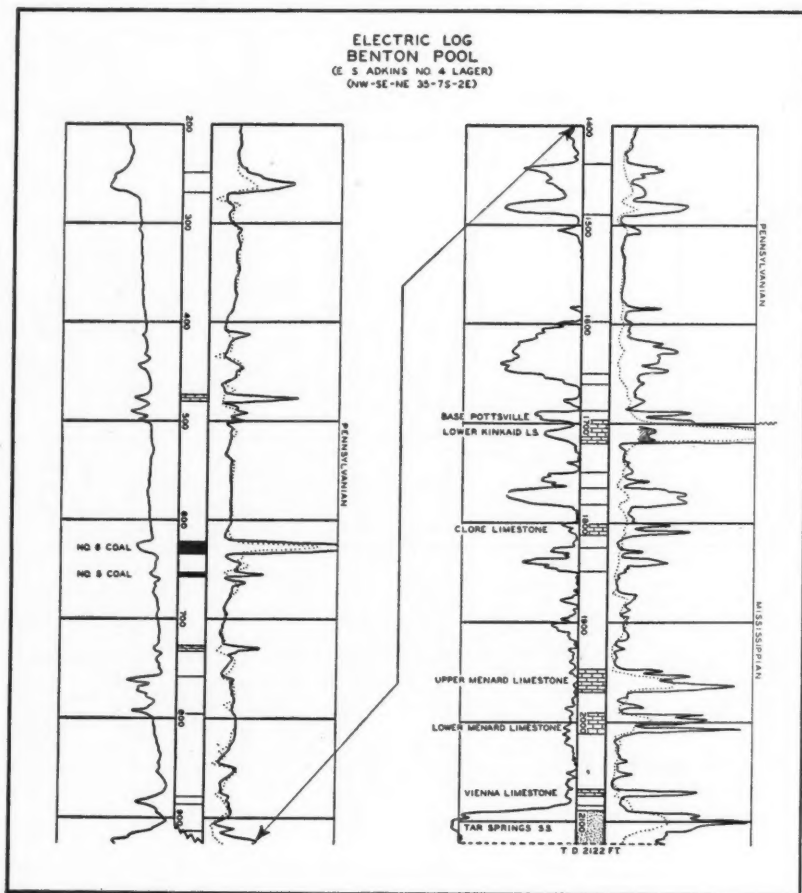
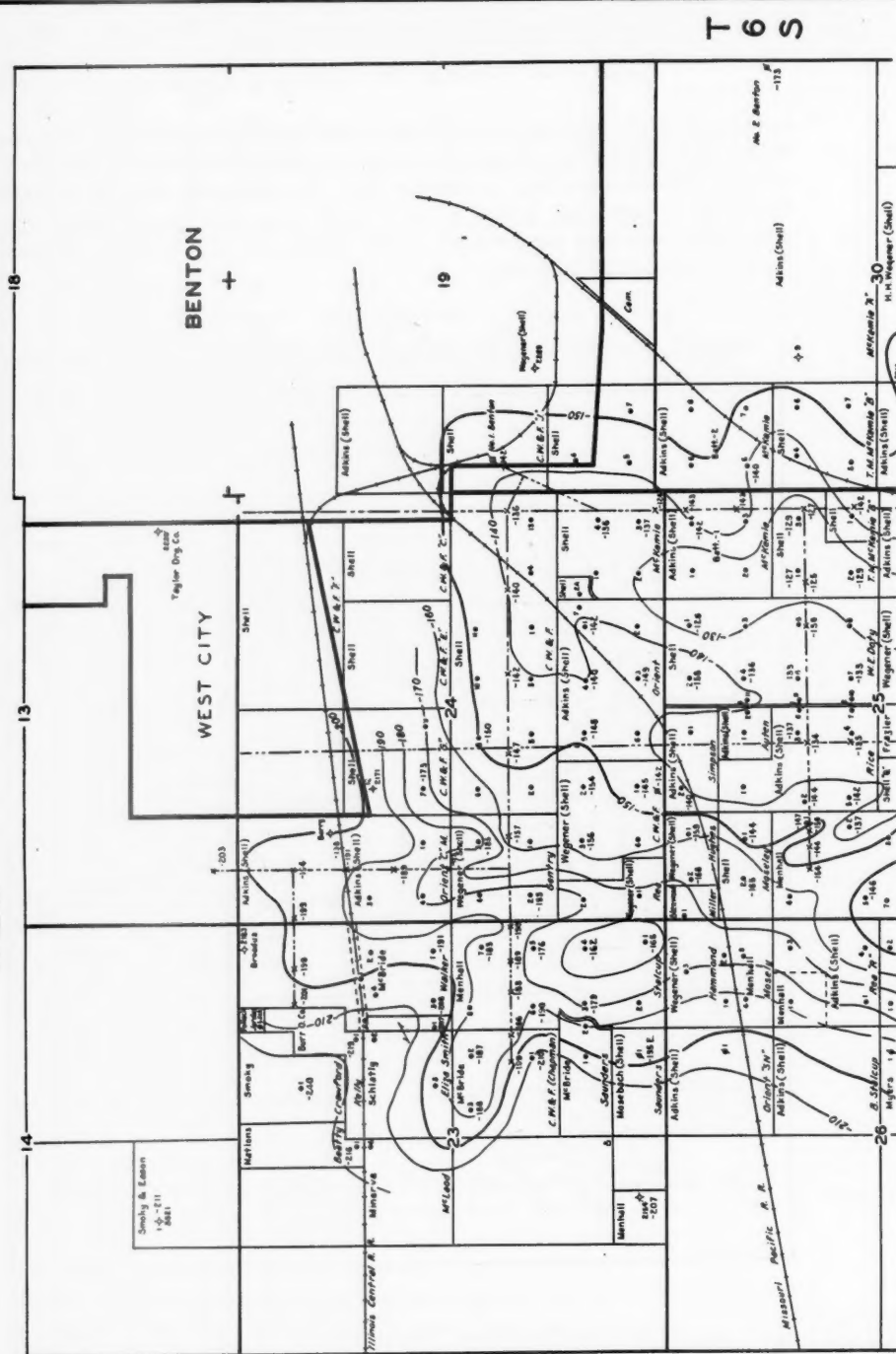


FIG. 4.—Type electric log, showing geologic section.

R2E

R3E



T6S

T6S

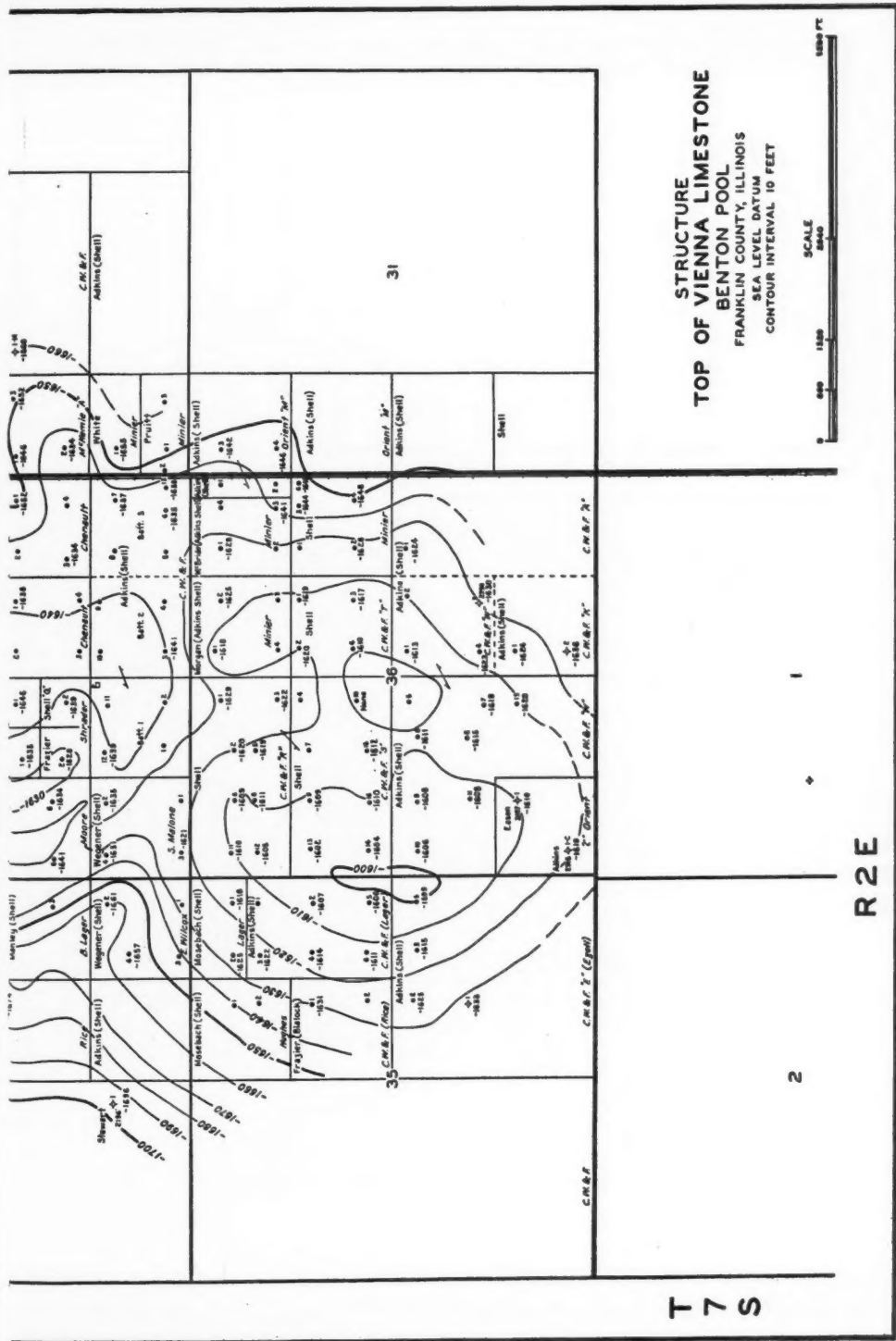


FIG. 6.—Structure map of Benton field, contours on Vienna limestone.

sandstones of Pennsylvanian (Carbondale) age. The Shoal Creek limestone is absent in the area, but is found at a depth of about 200 feet, approximately 4 miles east. No. 6 coal occurs at depths of 500-600 feet throughout the field and has been, or will be, mined throughout the field. In the Benton field this coal is 9 feet thick. Fifty feet below No. 6 is No. 5, or Harrisburg coal, 4 feet thick, and both must be protected in drilling operations.

Pennsylvanian beds, chiefly shale and sandstone, extend to a depth of 1,000 feet, and are underlain by the coarse sandstones and sandy shales of the lowermost Pennsylvanian Pottsville beds. These in turn rest on the uppermost Chester beds, in this area, the Kinkaid limestone.

The character of both Pennsylvanian and Chester beds is best shown by the section, Figure 4, and accompanying legend.

STRUCTURE

The structure of the Benton field is shown in Figures 5 and 6. A broad anticlinal flexure extends from a point just north of the Cottage Grove fault, northward along the east line of R. 2 E., through West Frankfort and through the western part of Benton, a distance of more than 14 miles. Local folding and favorable sand conditions on this axis have combined to produce, from south to north, the pools designated as West Frankfort South, West Frankfort North, Benton, and North Benton. Only Benton is of considerable size, producing areas in the other pools being small, although individual wells are of fair size.

On the west, north, and east sides of the field, dips as measured on the Vienna limestone carry the producing sand below water level, although the sand itself apparently passes into shale on the northeast within the limits of Benton and West City. The south dip of about 30 feet is inadequate to produce a full closure, but combined with abrupt facies change there is effective closure of at least 65 feet, and saturated sand of that thickness is present (Fig. 7).

The close similarity of the structure of No. 6 coal to that of the Vienna limestone immediately above the producing sand may be seen by comparing Figures 5 and 6. It seems obvious that much, if not all, of the folding mapped on the Vienna must have taken place in post-Carbondale time.

The relation of Vienna to deeper structure is unknown, as no wells within the field have been deepened and only four edge wells were drilled below the Tar Springs, their distribution being inadequate to show the structure. The discovery well, Orient No. 1, was drilled to the Fredonia limestone, but inasmuch as it was known that a well could be made in the Tar Springs, the hole was drilled without testing or carefully examining any lower sands. The electric log indicates thin streaks of possibly saturated sand in the Benoist and Aux Vases, and a possible occurrence in the Levias limestone, but this was prior to the use of the wide lateral curve and full reliance can not be placed on these results. Inasmuch as several lower zones, including Benoist-Paint Creek, Aux Vases, Levias, and Rosiclare, are productive at West Frankfort and North Benton, it is probable that some of these may contain oil at Benton.

SANDSTONE RESERVOIR

The greatest thickness and best development of Tar Springs sandstone in southern Illinois appears to be in a belt extending from Ziegler through Buckner and northeastward into the Ina area of Franklin County. Benton is east of this belt, where electric logs indicate as much as 105 feet of solid sandstone, nearly filling the entire interval between the Vienna and Glen Dean limestones. A tongue of this sand body extends across the Benton anticline, being cut off abruptly by "shaling-out" on the south and on the north and northeast. The change from

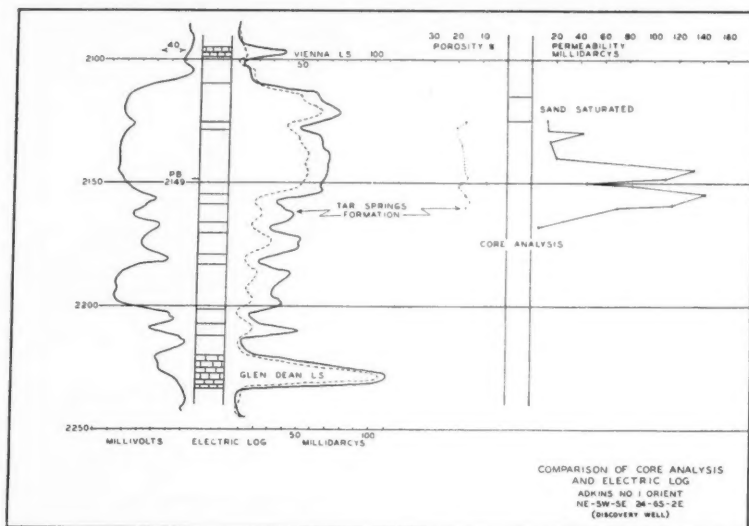


FIG. 8.—Core analysis compared with electric log. Tar Springs sand.

shale to sandstone is rather abrupt (Figs. 9 and 10) and occurs within the span of one location, or 660 feet. It clearly is not a thinning-out from the top downward, but strictly a lateral process, and occurs from top to bottom of the formation at the same point. It may be left to the sedimentationists to explain the process.

Presence of the thick body of Tar Springs sandstone on the west seems best to explain the fact that the most notable influx of water into the reservoir (with some extraordinarily high recoveries) has taken place on the west side of the field.

In the proved limits of the field, comprising approximately 2,400 acres, no well has failed to encounter sand of sufficient permeability and porosity to produce. Lithologic variations are illustrated in Figures 9 and 10 which show broadly the sand character as determined from electric logs. Study of cores reveals a considerable number of thin and probably discontinuous shale bands in the sands. In a few wells drilled on the Adkins and Wegener-Chenault leases, in the

NE. $\frac{1}{4}$ of Sec. 25, a thin lens of dense gray, slightly sandy limestone was found approximately 25 feet below the top of the sand body.

Generally 10 feet of dark shale separates the Tar Springs sandstone from the Vienna limestone, but this interval varies locally from zero to 20 feet. Thin coal seams, not exceeding 4 inches, occur locally at the top of the sand, but have not been noted below the top. Most of the sand is of fine to medium grade, but there

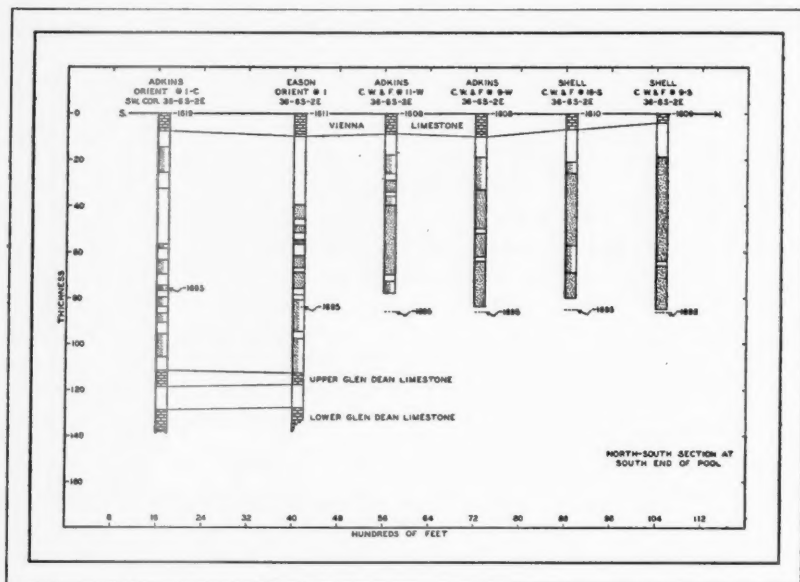


FIG. 9.—Cross section southwest side of field.

are some coarse bands. The grains are poorly rounded, and generally subangular. Cementation is more commonly siliceous but calcareous sands are not rare. Cross-bedding is commonly noted in cores.

Porosity.—Porosity of core samples ranges from 13 per cent to 25 per cent, the average being near 20 per cent. It is variable both horizontally and vertically (Fig. 4).

Permeability.—Horizontal permeability is highly variable, ranging at least from zero to 835 millidarcys. A few samples have been reported to exceed this figure, but seem to be exceptional. The average permeability of a large number of samples is 80 millidarcys, based on cores from ten scattered wells. This may be taken as representative of the reservoir as a whole.

Vertical permeability data are scant, but an average of those available, after eliminating the extremes, is about 30 millidarcys, or one-third of the horizontal

value. The effective vertical porosity is further reduced by the presence of thin shale streaks, and fluid movement within the reservoir must be lateral, rather than vertical.

DEVELOPMENT

Drilling.—All wells in the Benton field are drilled through (a) an abandoned

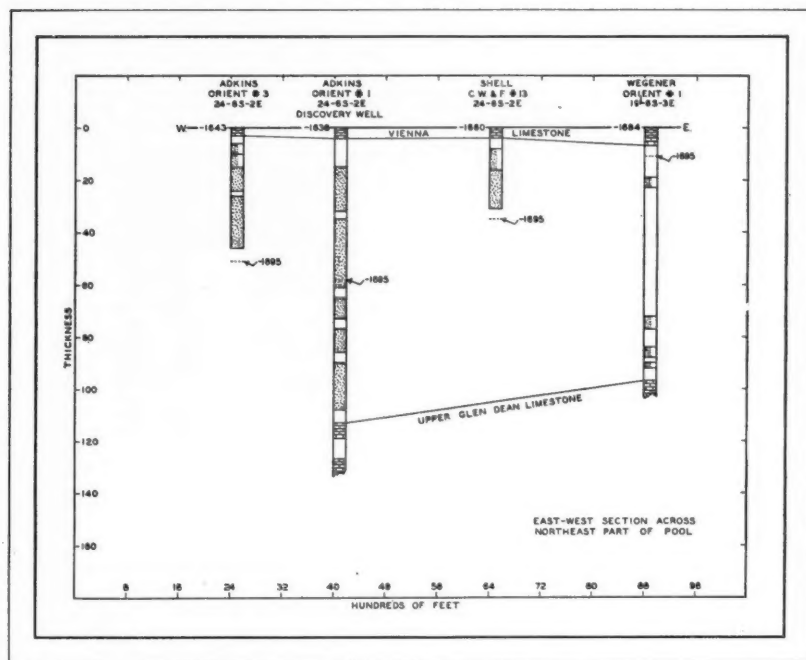


FIG. 10.—Cross section northeast side of field.

mine, (b) an operating mine, or (c) virgin coal, 9 feet thick, contiguous to an operating mine.

Certain exceptional conditions encountered in the area must be discussed, together with the means for their solution.

A. Drilling through abandoned mine or sheared pillar.—Drilling through an abandoned mine or the worked-out and caved workings of an active mine is the most difficult and expensive operation. This is because the abandoned mine may have inaccurate surveys, or surveys not correlated with the surface surveys. Thus, the exact location of underground pillars can not be projected on the surface. Furthermore, with the passage of time, openings become flooded, pillars are

sheared by caving, and roof fractures develop as far as 75 feet above the mine level. When starting a well in such areas, preparations are made for "hitting the mine" and precautions taken to prevent trouble.

In this case, the ordinary amount of surface casing, 12½ or 15 inches in diameter, is set, this generally being 60-100 feet, and cemented to the surface. Drilling proceeds as usual to a point 100 feet above the coal horizon, after which great care

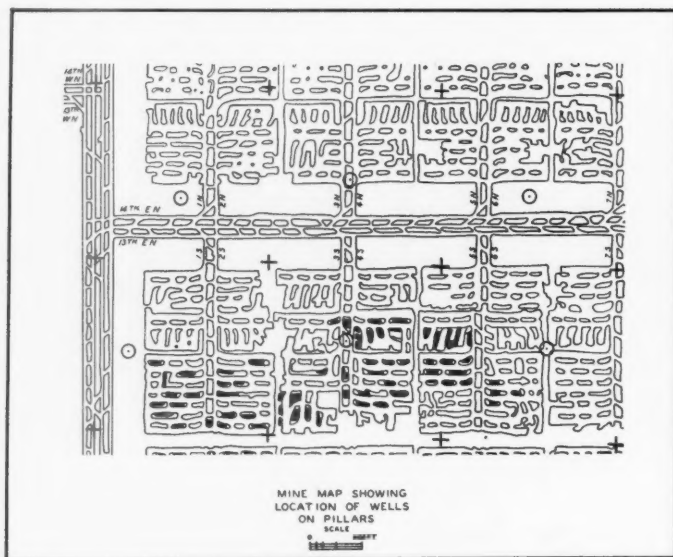


FIG. 11.—Mine map showing locations of wells in pillars.

is taken, with the driller controlling the brake at all times and the pit being constantly watched. First warning that the open mine has been encountered generally is loss of returns. The next may be a sudden drop of the kelly. If an opening is encountered, the pump is shut off, or cut to very low speed, and the hole is drilled 50 feet below the mine level. The entire hole is then reamed to a size sufficient to set 10-inch casing, which is cemented as shown in Figure 4b, the cement thus extending a distance of 50 feet below the mine level, and from the mine to the surface. As a rule, the water in a flooded mine is sufficient to permit drilling the lower part of the hole dry, but if not, the pumps must be operated, slowly.

B. Drilling through operating mine.—In drilling through an active mine, every precaution must be taken, but inasmuch as locations are centered only over pillars known to be intact, and surveys can be checked, there is little real danger

(Fig. 12). Pillars of large size are selected, generally where not less than 20 feet of coal surrounds the well. At greater depths the amount of protection should be greater, but this has been ample at 500-600 feet in Illinois.

C. Drilling through virgin coal.—Where development proceeds in virgin territory contiguous to an active mine, locations are selected at points which will be

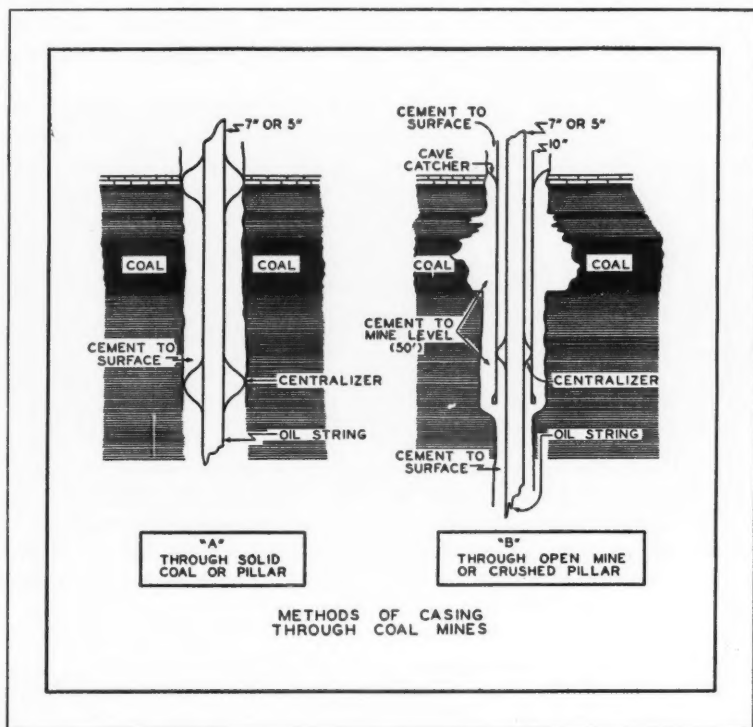


FIG. 12.—Sketch showing method of drilling through mine.

over main pillars when operations reach that locality. This necessitates laying out the mine workings far in advance of active operations, and also necessitates close cooperation of oil operators and coal companies. Such cooperation was notably effective in the Benton field, where the Chicago, Wilmington, and Franklin Coal Company owned all mineral rights, not only of the area under the field, but of many thousand acres adjacent.

No problem is involved when the pillar is adequate, or when penetrating virgin coal. Protection of the mine is assured by using centralizers on the oil string

immediately above and below the coal to produce a uniform distribution of the cement, and by circulating cement to the surface.

RESERVOIR DATA

Pressure.—No bottom-hole pressures were taken in the field until the spring of 1943, after more than 13 million barrels of oil had been produced. Calculations based on all known factors indicate that the original pressure was slightly in excess of 800 pounds per square inch. The early wells filled to the surface with oil of 41° gravity, but did not flow.

Gas-oil ratio.—Gas-oil ratios were not generally determined in the early life of the field, but all available evidence points toward a figure of approximately 125 cubic feet per barrel in the discovery well, and this may be taken as typical for the field. Five years later the figure had risen to an average of 600–700 cubic feet. The oil was undersaturated and no original gas cap was present. Gas-oil ratios increased as follows.

GAS-OIL RATIOS, BENTON FIELD

January, 1941	125	(1 well)
January, 1942	400	(1942–1946 data from same group of 65 wells)
January, 1943	637	
January, 1944	731	
January, 1946	716	

Water.—Practically all wells produce small amounts of water, probably connate, and this is removed in heaters. Some wells on the west side of the field yield large volumes of water, which may be either edge or bottom water. The water level is at –1695 throughout the field. The following analysis of Tar Springs water from the Adkins Orient lease is typical of the field, although there is some evidence, based on analyses made in May, 1943,⁴ that a decrease in chlorides and total solids was then evident in passing from northwest to southeast. This suggests that gradual encroachment of edge water may be altering the character of the water in the field by infiltration.

Character of oil.—The first oil produced was of 41.7° A.P.I. gravity, but because of gradual loss of gas in solution, the gravity has declined to 38°–39°.

Production methods.—The general practice has been to set casing of 7 or 4½ inches outside diameter at the top of the highest saturated sand, and cement to the surface with 550–600 sacks of cement. Some operators, after early tests had determined the water level to be –1695, cored to this point, ran an electric log to confirm the sand top, and subsequently cleaned out and shot with an average of one quart of nitroglycerine per foot of sand. Others took a single 10-foot core after checking the sand top, set casing, and “tailed in” to a point at or near water level, before shooting. There has been no evidence that production under the two methods differed greatly.

⁴ Carl A. Bays, “Production Conditions in the Benton Field,” unpublished manuscript, Illinois Geol. Survey, May, 1943.

All wells were placed on pump immediately. Power originally was from individual units, the Shell Oil Company using electric motors, and other operators installing gas motors. At present several leases are operated on central-power units, having been converted after flush production declined.

All leases are equipped with water-treating units, application of heat being sufficient to remove the small amount of emulsion commonly present. About half of the produced water is being disposed into the lower Pottsville sandstone and the lower Tar Springs sand. The latter disposal well is outside the boundary of the

ANALYSES OF TAR SPRINGS WATER, BENTON FIELD*
Wells 1-7 on Adkins Orient Lease, Sec. 24, T. 6 S., R. 2 E.

Constituents	Parts Per Million		Hypothetical Combination	Parts Per Million	
	May 8, 1941	May 11, 1943		May 8, 1941	May 11, 1943
NH ₄	1.4	15.1	NaNO ₃	9.7	8.5
Na	36,511.9	34,667.0	NaCl	92,809.2	88,119.0
K			NH ₄ Cl	4.1	44.9
Ca	5,383.0	5,145.0	MgCl ₂	6,762.0	6,414.0
Mg	1,727.0	1,638.0	CaCl ₂	14,858.1	12,249.0
SiO ₂	10.0	16.0	CaSO ₄	29.1	
Non Vol.	1.0	5.0	CaCO ₃	17.0	
Fe (filtered)	19.2	20.0	SiO ₂	10.0	16.0
Al ₂ O ₃	35.5	14.4	Fe ₂ O ₃	27.5	28.6
Mn	1.8	0.0	Al ₂ O ₃	35.5	14.4
SO ₄	28.8	0.0	M ₂ O	2.3	0.0
Cl	70,822.0	67,357.0	Non Vol.	1.0	5.0
NO ₃	7.1	6.2			
HCO ₃	20.7		Total	114,565.5	108,899.0
Fe (unfiltered)	48.1	30.0			
Fe ₂ O ₃ (unfiltered)	68.6	42.9			
Total solids	118,714.0	113,300.0			

* Samples collected from heat treater. Analyses by O. W. Rees, Illinois Geological Survey, and used by permission.

producing area and utilizes a dry hole in Sec. 12, T. 7 S., R. 2 E., a mile south of the field.

Production and reserves.—Oil originally present, and recoverable by usual production methods has been estimated to be approximately 26,000,000 barrels, of which 18,656, 892 barrels had been produced to June 1, 1947.

Recoveries per acre-foot cover a wide range, certain areas of shaly or tight sand having indicated ultimate recoveries of only 150 barrels per acre-foot, while other tracts, underlain by more porous sand and affected by incipient water drive, have already produced almost 500 barrels per acre-foot. Highest recoveries have generally been accompanied by greater amounts of water, and rather obviously are the result of a partial water drive.

The productive area of the field is 2,400 acres, and the average thickness of producing sand is 39.4 feet, indicating an average recovery of 275 barrels per acre-foot. As the wells generally are on 10-acre tracts, this is 108,350 barrels per

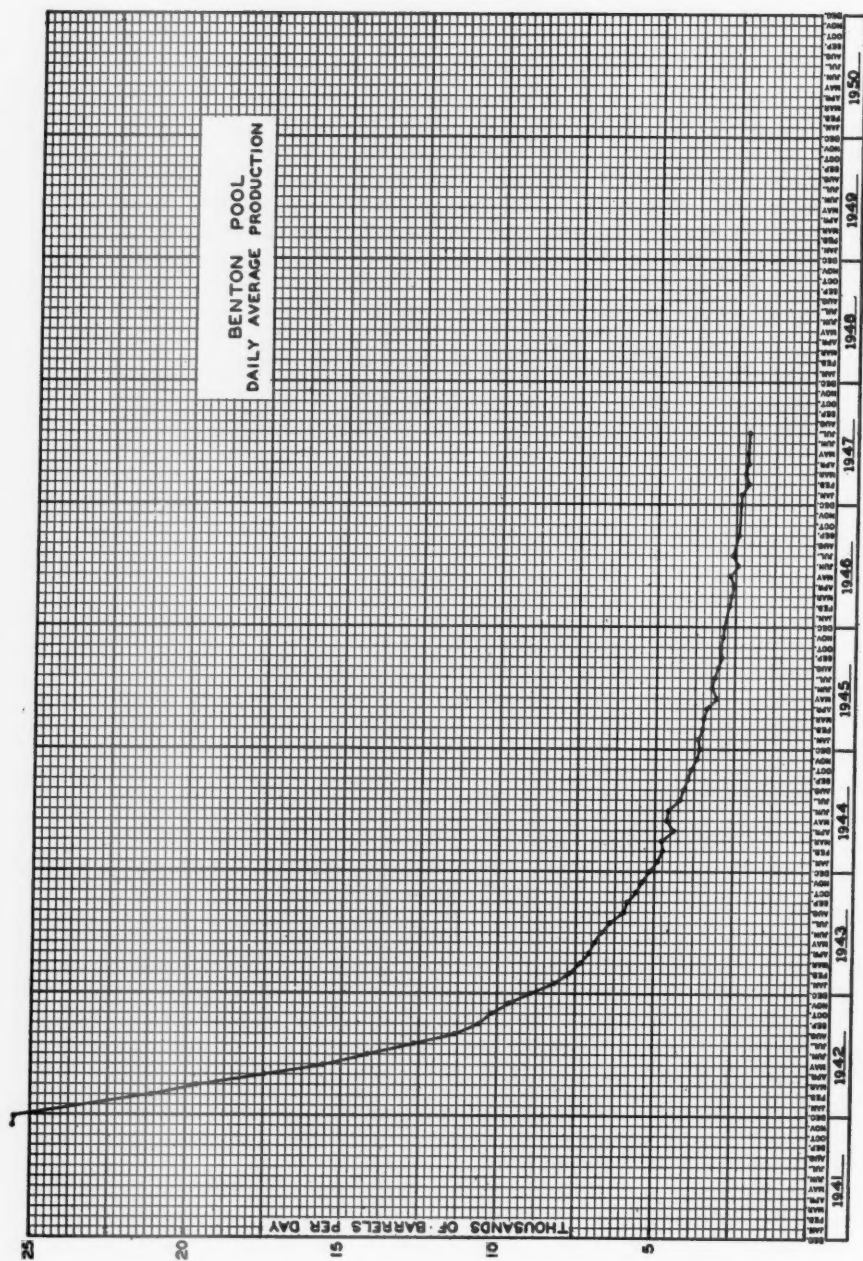


FIG. 13.—Production curve of Benton field (rate-time).

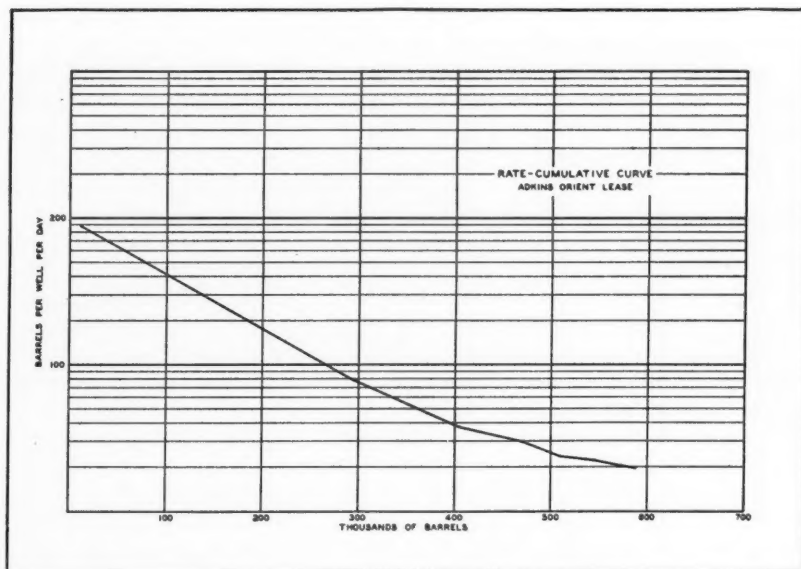


FIG. 14.—Production curve of Benton field (rate-cumulative).

well, or a recovery of 10,835 barrels per acre for the entire field. Certain tracts will produce 17,000–18,000 barrels per acre.

PRODUCTION BY YEARS
(Barrels)

Year	Daily in December	Gross for Year	Cumulative to December 31
1941	25,682	6,989,570	6,989,570
1942	8,966	5,386,388	12,375,958
1943	5,064	2,333,904	14,709,862
1944	3,535	1,555,585	16,268,428
1945	2,810	1,147,542	17,415,989
1946	2,306	912,888	18,328,877
1947	2,123 (May)	328,015 (5 months)	18,656,892 (to May 31)

Other possible producing formations.—No well in the field produces from a sand deeper than the Tar Springs, and these beds have not been tested. The discovery well, Orient No. 1, was drilled to the St. Louis limestone, and the electric log indicates possible saturation in the Aux Vases sandstone and Levias limestone, but these were not tested as it was known that a good well could be made in the Tar Springs.

Five wells, including Orient No. 1, showed saturated sand between the upper and lower Kinkaid limestones, and at least two are now producing from these

sands through perforations. The production, however, is not large, and the productive area will not exceed 50 acres.

Two wells, one on the west and the other on the east side of the field, have found thin saturated sands at the base of the Pottsville, but drill-stem tests indicated a high water content and no commercial production is anticipated from this source. These were: Myers' Rice No. 1, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 26, T. 6 S., R. 2 E., 1763-1768 feet (core 1762-1779); Adkins' McKemie No. 1, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 25, T. 6 S., R. 2 E. (1803-1813 feet, electric log; not cored).

Reservoir energy.—Undersaturation of the oil is obvious as oil of 42° A.P.I. gravity at 800 pounds pressure could well retain in solution more than 125 cubic feet of gas per barrel. All gas present, therefore, performed useful work in bringing oil out of the sand. Unfortunately, none of the gas produced during the flush period was returned to the reservoir, and none has been returned since.

Several facts point toward the presence of at least a partial water drive. These may be summarized as follows.

(a) Tracts having highest recoveries per acre-foot also produce largest amounts of water.

(b) Most of these tracts are on the west edge of the field, adjacent to the extensive body of water-bearing Tar Springs sand, which is downdip from the field.

(c) Most of tracts show evidence of water drive in the fact that their rate-cumulative curves, drawn on semi-logarithmic paper, show a definite upward concavity. In other words, rate of decline is at a decelerating ratio somewhat less than normal in some leases, normal being considered that of the field as a whole.

(d) High-recovery leases, which also are producing large amounts of water, have already produced nearly 50 per cent more oil than is theoretically recoverable.

It is not believed that a complete or effective water drive will ever be developed naturally, but the evidence suggests strongly that artificial water drive may ultimately be practical.

SUBMARINE SEDIMENTARY FEATURES ON BAHAMA
BANKS AND THEIR BEARING ON DISTRIBUTION
PATTERNS OF LENTICULAR OIL SANDS¹

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ABSTRACT

In flying from Miami to eastern Cuba, the route lay for a distance of 208 miles over the Bahama Banks. For the entire distance the sea bottom was visible through the water.

A striking pattern of bars and giant ripples was revealed that may aid in explaining the distribution pattern of certain lenticular oil and gas sands that seem to have been deposited at considerable distance off-shore.

The patterns on the Bahama Banks were photographed and mapped by photogrammetric methods. The pattern revealed is compared with that of the distribution of gas and oil sands in part of the Clinton sand area of Ohio. Remarkable similarity in pattern is revealed, but the scale of the Bahama Banks features is considerably smaller.

In flying from Miami, Florida, to Antilla in eastern Cuba, the route lay over the Bahama Banks for a distance of about 208 miles, in all of which the water was so shallow that the sea bottom could be seen distinctly. A striking pattern of bars and giant ripples was revealed, and a photographic record was obtained sufficiently good to permit of leisurely study. Since the approximate flying height (11,000 feet) was supplied by the pilot, it was also possible, by photogrammetric methods, to map the pattern and approximate dimensions of the features of greatest interest. Since no horizon is shown on the photos the mapping could not be exact, but it is believed to be essentially correct.

These ocean-bottom patterns are of particular interest to the oil geologist because they offer clues to the nature of the lenticularity of certain oil and gas sands that do not fall into the classes of channel sands or of off-shore sand bars of the common type.

The United States Coast and Geodetic Survey Hydrographic Chart (No. 1002, Straits of Florida, 1941) shows depths along the line of flight ranging from 6 feet in spots along the margins of the Banks to a maximum of 33 feet. Over the greater part of the route between the western rim and Hurricane Flats the depth ranges from 18 to 21 feet; on Hurricane Flats it ranges from 12 to 15 feet; and between Hurricane Flats and the southeastern rim it averages about 27 feet. All along the southwestern and southern margins of the Banks is a relatively narrow rim where the water is shallower than on the platform immediately behind the rim.

As the edge of the Bahama Banks was approached from the west it appeared as an almost perfectly straight line extending both north and south as far as one could see from a height of 11,000 feet, and was marked by an abrupt change from the cobalt blue of the deep water of the Straits of Florida to the turquoise green of the shallows, under which the bottom patterns were distinctly visible (Figs. 2, 3, 4, 5).

¹ Read before the Association at Chicago, April 3, 1946. Manuscript received, March 12, 1948.

² Department of geology, University of Cincinnati.

In order to determine the actual trends of these bars and their approximate dimensions, the map (Fig. 8) was made by the Canadian grid method from the photos of Figures 3, 4, and 5. The northern third of the map portrays the features photographed in Figure 3, and most of the remainder appears on both Figures 4 and 5. The map was oriented with respect to the trend of the western edge of the Banks in this locality as represented on the Hydrographic Chart.

The bottom on the western shoal of the banks, as revealed on the three photographs mentioned, shows a pattern of discontinuous and anastomosing bars having a curious combination of trends, one approximately parallel with the western edge of the Banks (here trending about 5° W. of North) and another diagonal to the edge at an angle of 40° – 60° to it, that is, trending about N. 42° W. to N. 60° W.

These bars are superposed on the slightly elevated rim already mentioned, where the water is considerably shallower than over other parts of the Banks crossed by the line of flight. This western shoal rim, whose inner or eastern edge is clearly visible in Figure 5, is shown by the map (Fig. 8) to be about $4\frac{1}{2}$ miles wide where crossed by the flight line. On it, according to the Hydrographic Office chart, the water is 6–12 feet deep while away from the margins it ranges, along the route of the flight, from about 20 to 35 feet.

The shoal as a whole may be a former coral reef, but no evidence was noticed of an irregular coral surface or of the presence of living coral, and the bars on its top, from their pattern, may be judged to be composed of material having the texture of sand. Whether it is a lime sand composed of shell and coral fragments or is lime oölite is not known to the writer, but it undoubtedly is one or the other, for no source is available for sand of other than calcareous nature. Agassiz,³ referring to an area very close to that where our photographs were taken, says,

About 25 miles south of Orange Cay there is a narrow belt of sand ridges running nearly parallel with the 100-fathom line for a length of about 18 miles. These banks and bores are limited to the area north of the great marl deposit to the west of Andros . . .

In describing a traverse from Billy Island to Orange Cay, Agassiz says (page 53), When five miles from the edge of the bank the bottom was quite clear of mud and marl and was composed mainly of nicely rounded particles of coral sand.

That some of the bars on the Bahama Banks may be composed of lime oölite is suggested by statements of Davis⁴ to the effect that lime oölite is forming in the lagoons of coral regions and is the most abundant type of sediment around the Florida keys and at various places in the Bahamas. Vaughn⁵ also gives evidence

³ Alexander Agassiz, "A Reconnaissance of the Bahamas and of the Elevated Reefs of Cuba in the Steam Yacht 'Wild Duck,' January to April, 1893," *Bull. Mus. Comp. Zoology at Harvard College*, Vol. 26, No. 1 (1894), p. 38.

⁴ William Morris Davis, "The Coral Reef Problem," *Amer. Geogr. Soc. Spec. Pub.* 9 (1928).

⁵ Thomas Wayland Vaughan, "Preliminary Remarks on the Geology of the Bahamas, with Special Reference to the Origin of the Bahaman and Floridian Oölites," *Carnegie Inst. Washington*, Vol. 5, Pub. 182 (1914), pp. 47–54.

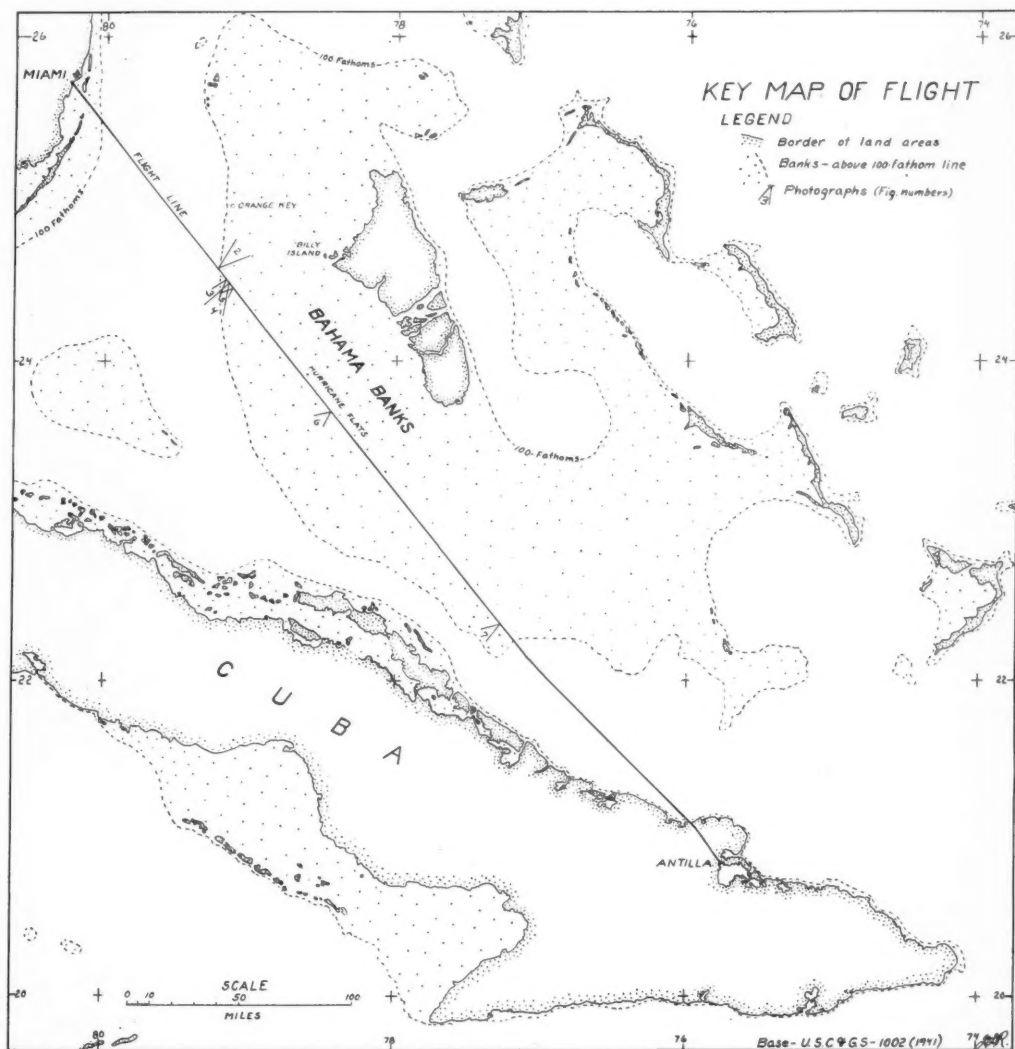


FIG. 1.—Key map of flight, Miami, Florida, to Antilla, Cuba.



FIG. 2.—Looking northeast from over west edge of Bahama Banks (approx. $24^{\circ}34'N.$, $79^{\circ}24'W.$) Irregular giant ripples cover a large area and trend diagonally to west edge of Banks, which is indicated by white guide lines on left and lower margins of photograph.

This and succeeding five pictures were taken from elevation of approximately 11,000 feet, and features shown are entirely sub-aqueous. Water depths on Banks range from 6 to 35 feet, but only 6 to 15 feet in this area.

that oölite is being formed in those regions from flocculent calcium carbonate ooze.

The pattern of the bars suggests the work of a combination of wave action with that of the current of the Gulf Stream flowing north through the Straits of Florida, together, possibly, with the effect of tidal currents across the shallow rim of the bank into and out of the large lagoonal area constituting the main body of the Bank.

Between the bars are irregular dark green patches which appeared to be seaweed. They are well shown in Figure 3.

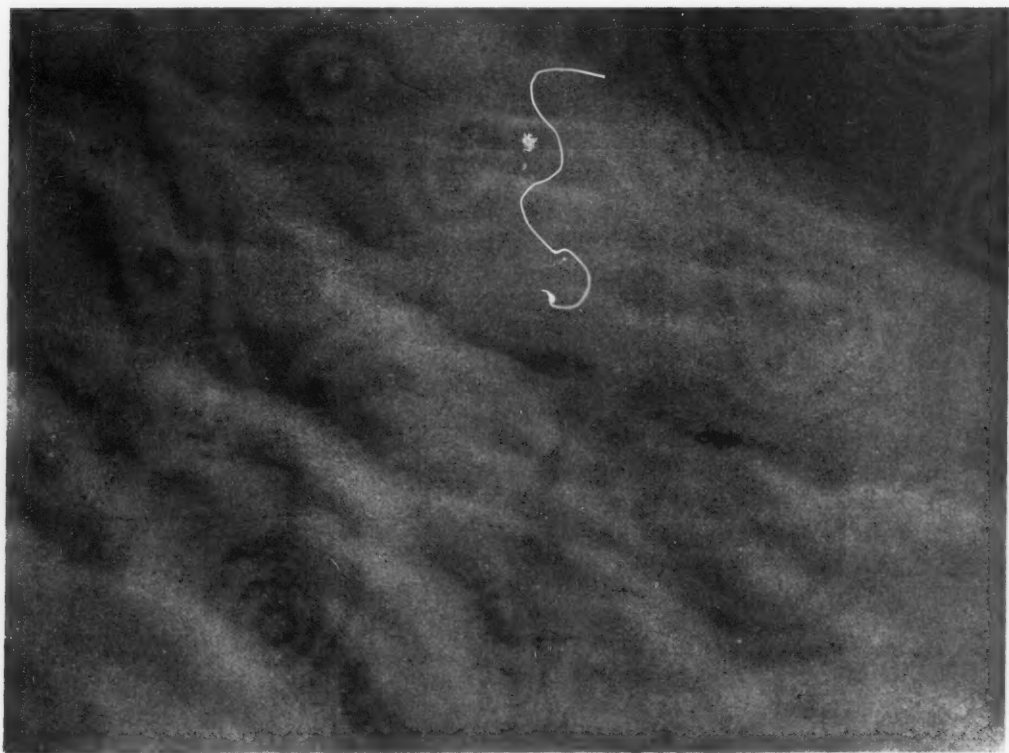


FIG. 3.—Detail of sub-aqueous features on marginal rim at western edge of Bahama Banks. Southwest from approximately $24^{\circ}30'$ N., $70^{\circ}11'$ W. Deep water at western edge of Banks is clearly shown by darker shade at upper right. Dark patches are seaweed in lower places of Banks.

East of the western shoal rim, the water is deeper and the bottom is generally rather featureless except that at one place 20–25 miles beyond the site of Figure 5 narrow, scattered linear bars were noted trending about S. 60° W. Beyond them, the bottom continued visible, but showed no noteworthy features until we came over the area known as Hurricane Flats, extending 15 miles or more along the route on both sides of the site of Figure 6. Over that area the depth of the water is recorded on the Hydrographic Chart as 18–21 feet. The bottom is distinctly visible (Fig. 6), and has a pattern of giant ripples vaguely aligned approximately east and west (probably between N. 70° and N. 90° W.). The pattern is much like that of current ripples, but on a giant scale, and it is also not unlike that of irregular sand hills on land, such as may be found along the Cimarron River in western Oklahoma. The scale also seems to be approximately the same as that of the sand hills. As nearly as could be measured from the photograph, the

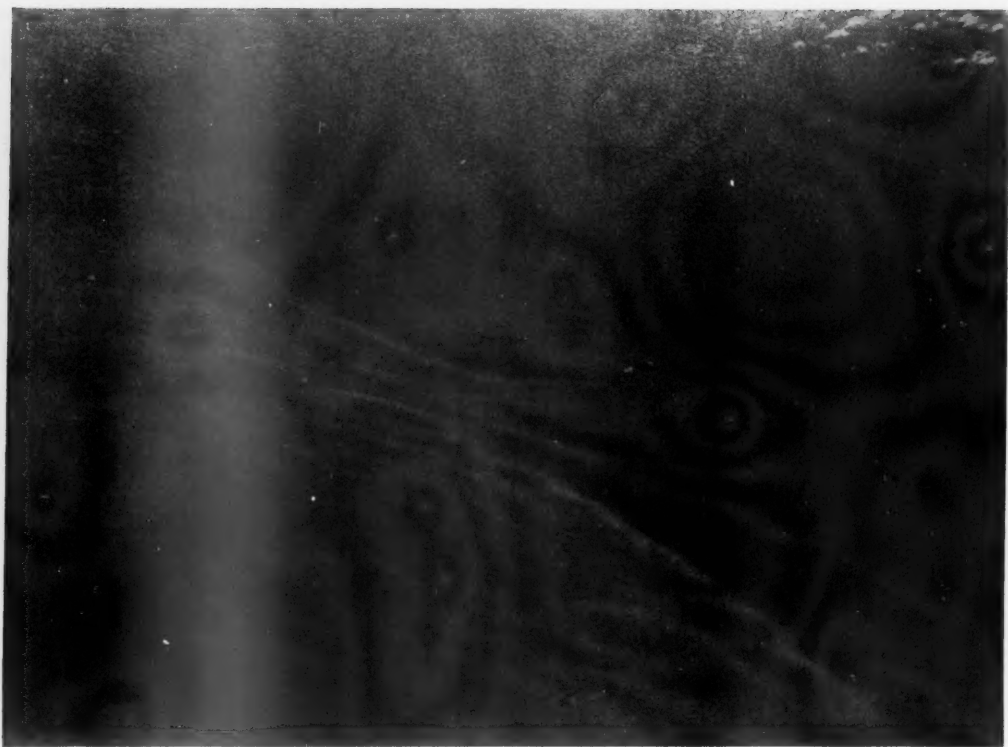


FIG. 4.—Looking south-southwest from point over eastern part of marginal rim (from about $24^{\circ}28\frac{1}{2}'$ N., $79^{\circ}9'$ W.). Straight western edge of Banks is clearly shown trending diagonally up across picture. Lower right corner of this picture joins upper left corner of Figure. 3

individual ripples or sandhill units in the foreground are about 600–750 feet across.

Along the route southeast of Hurricane Flats with its giant ripples, water is deeper (20–27 feet) and for a distance of about 50 miles the bottom shows a rippled pattern of much finer texture resembling that of the clouds of a “mackerel sky.” This appears to be made visible by dark-colored seaweed concentrated in the deeper spots. The “mackerel-sky” pattern itself shows a larger-scale blotchy pattern with the individual units a mile or more in size. After leaving the area described, the flight was over deeper water (up to 35 feet) where the bottom was barely visible but still was vaguely mottled.

The route was then over the shoal rim along the southeastern border of the banks, which was nearly 20 miles wide along the route, but probably somewhat less than that if measured at right angles to the 100-fathom line.

On this marginal shoal, distinct subaqueous bars occur, as shown in Figure 7

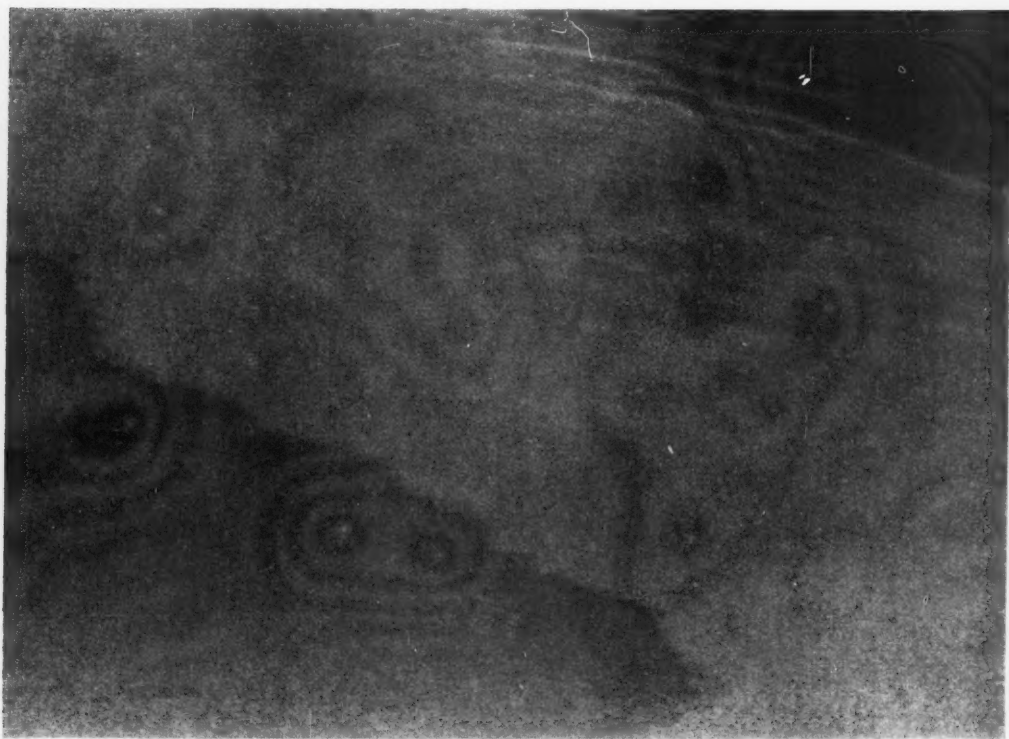


FIG. 5.—Looking southwest across western marginal rim of Bahama Banks from approximately $24^{\circ}26' \text{ N.}$, $79^{\circ}7' \text{ W.}$ Deep water at west edge of Banks shown at upper right. Eastern edge of marginal rim clearly shown in lower left. Sand bars at upper right can be identified a little below center of Figure 4.

Photographs of Figures 3, 4, and 5 were used for constructing the map of Figure 8.

and on the corresponding map (Fig. 9). Their trend appears to be approximately that of the Banks a few miles south. They are narrow and discontinuous and appear to have been formed by wave action rather than by currents.

Several shoals along the southeastern rim have water so shallow that waves break on them, and a few rise slightly above water level.

On the southeastern side of the Banks along the line of flight the break-off into deep water is conspicuous, but not so abrupt as on the western side.

COMPARISON OF PATTERN OF SAND ACCUMULATIONS ON BAHAMA BANKS WITH THAT OF "CLINTON" GAS SANDS OF OHIO

The opportunity to look down through the water and to see the exact pattern of distribution of sand accumulations over a large area, as can be done when fly-



FIG. 6.—Giant ripples on Hurricane Flats where such ripples characterize a large area. Vague trend in upper left appears to be approximately east-west. Dark patches in background are cloud shadows. Could this be an area of submerged sub-aerial sand hills? Looking southwest from approximately $23^{\circ}41' N.$, $78^{\circ}27' W.$

ing over the Bahama Banks, offers a partial key to the understanding of certain lenticular sand bodies which have controlled the accumulation of oil and gas but which, like the accumulations on the Bahama Banks, do not fall into either of the well known types, namely, off-shore sand bars or stream channel deposits.

The pattern of sand masses on the Bahama Banks, especially those seen along their western margin (Figs. 2, 3, 4, 5), suggests comparison with the lenticular sand bodies of the Clinton formation of central Ohio in which gas is found. A few years ago, the writer had occasion to compile a map showing the distribution of some of those sand bodies in Knox County. They showed an irregular pattern that could not be interpreted as off-shore sand bars or as river-channel deposits, yet they were decidedly lenticular. The distribution of the gas corresponds with that of the sand. Where sand is thick, good gas wells were obtained. Dry holes

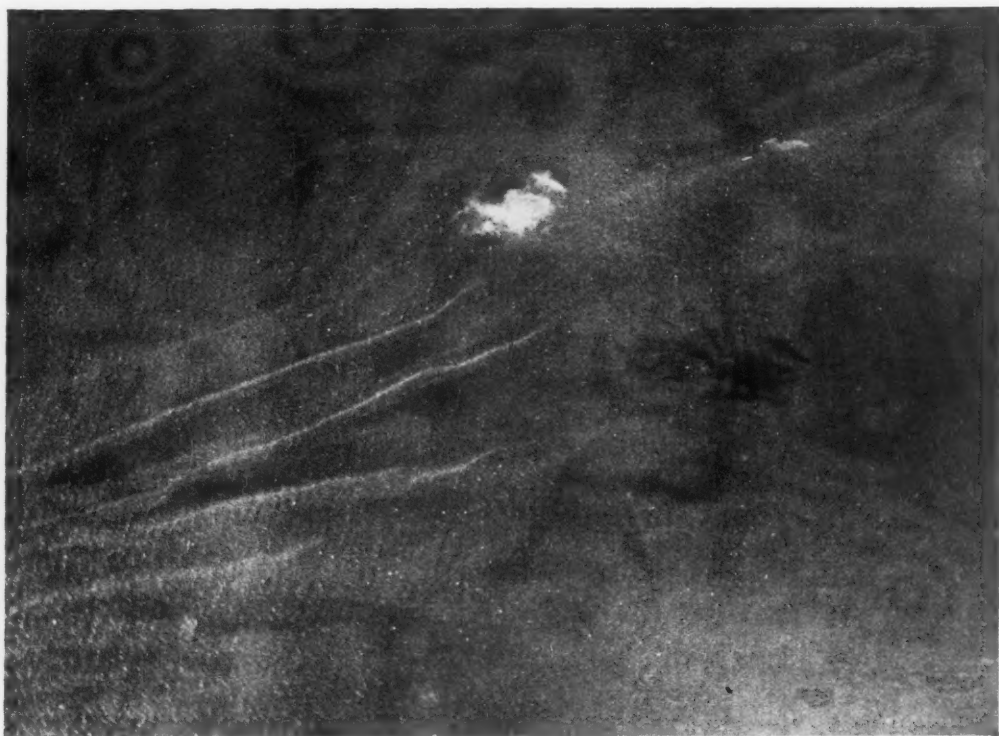


FIG. 7.—Bars, apparently shaped by waves, a few miles in from southeastern margin of Bahama Banks. Looking southwest from approximately $22^{\circ}21' N.$, $77^{\circ}17' W.$ Line of *en échelon* narrow bars, each a few miles long, continues trend here indicated for many miles, beginning with bar shown at upper right corner of photograph. (Pattern of light-colored flecks noticeable in left half of picture is not due to bottom features but to surface reflections from ocean swells.)

were generally so because of the sand being absent. Careful check of the structure showed that the prevailing homoclinal dip exerted no control over gas accumulation other than to cause the small amounts of oil that accompany the gas to accumulate at the downdip ends of the sand lenses.

In order to compare the pattern of the Clinton gas sands with that of the sand bodies on the Bahama Banks, this sand map of a part of Knox County is here reproduced (Fig. 10), on the same scale as that of the two maps of parts of the Bahama Banks (Figs. 8 and 9).

Comparison reveals a decided similarity in pattern, particularly with the area shown in the photograph (Fig. 3), and mapped in the northern third of Figure 8, but in the Clinton sands the pattern is developed on a scale approximately three times larger than on the Banks.

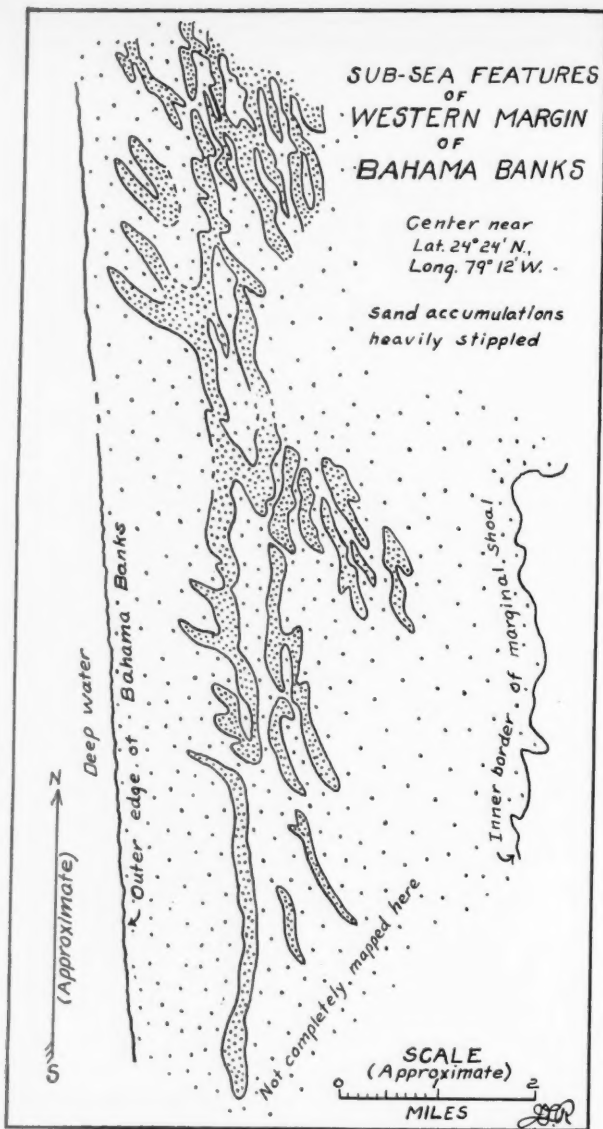


FIG. 8.—Map showing sub-sea features of western margin of Bahama Banks. Constructed by photogrammetry from photographs of Figures 3, 4, and 5. Scale approximate.

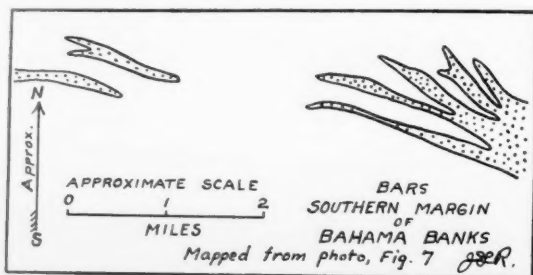


FIG. 9.—Approximate map constructed from photograph of Figure 7.

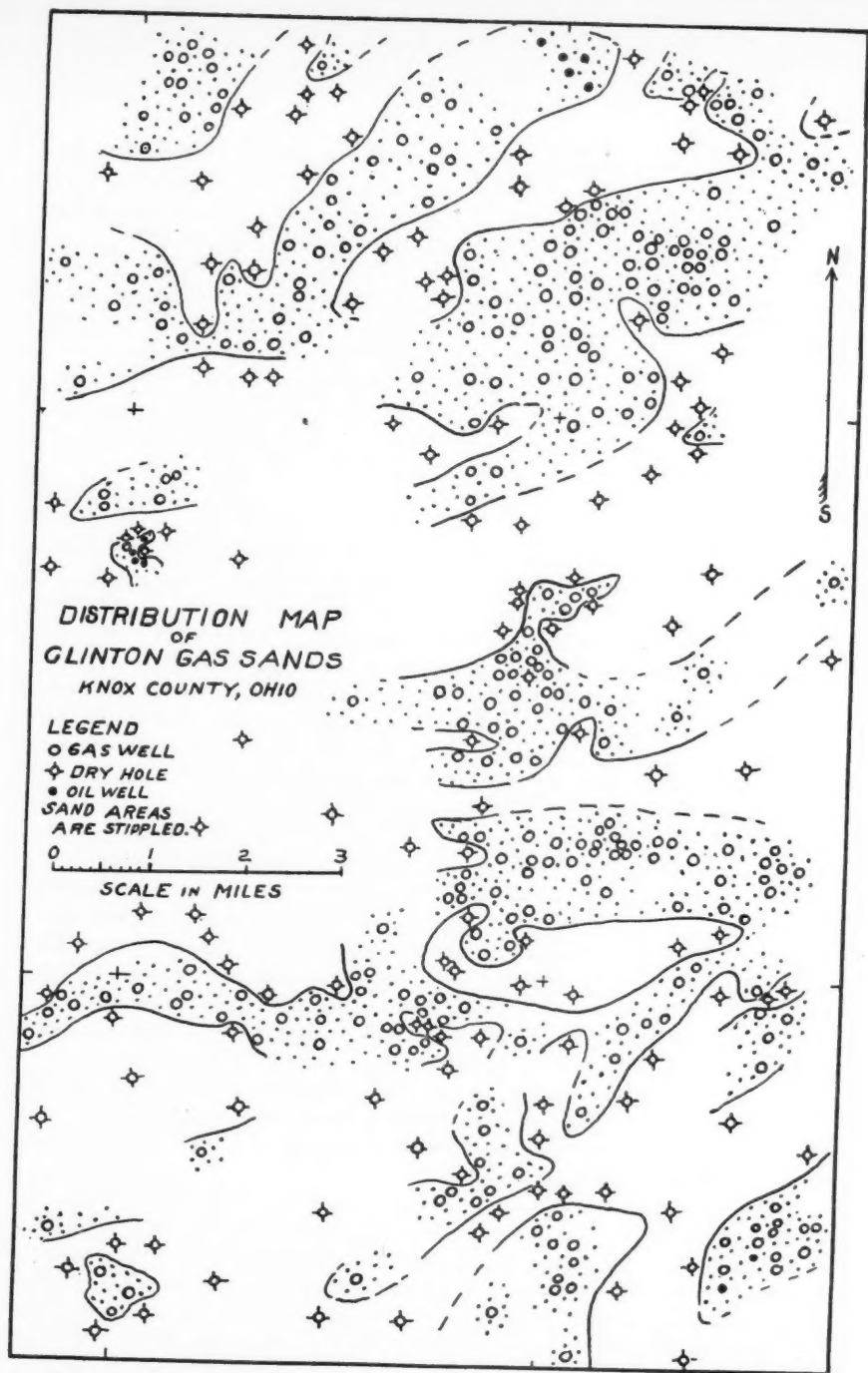


FIG. 10.—Sand map of area producing gas from “Clinton” sands in Knox County, Ohio. Scale is same as that of Figures 8 and 9. Stippled areas, those in which gas was found. In general, they correspond with areas where sand is present, for lack of gas production here is generally due to absence of sand. (Gas wells shown by circles and dry holes by standard dry-hole symbol of circle and cross.)

The Clinton sand map (Fig. 10) is a composite made without reference to the exact horizon of the Clinton in which the gas sand occurs. Consequently the sand bodies at any one horizon would not be exactly as there shown. Nevertheless, the general pattern of the sand lenses is almost certainly essentially correct.

The tie between the pattern of sand distribution in the two areas and the agencies producing that distribution, and the reasons why the pattern in one area is on a different scale than that of a similar pattern in the other are not fully understood, but possibilities which have come to mind are here recorded.

The pattern revealed in Figure 8 and in photographs 2, 3, 4, and 5, because of its anastomosing nature, its lack of continuity, and the large area covered by it (Figs. 2 and 3), seems definitely not to be due to wave action alone, but it may well be a product of a combination of wave and current action.

It is believed that the current of the Gulf Stream, here flowing northward and undoubtedly affecting to some extent the shoal water on the western rim of the Banks, combines with tidal currents flowing across the shoal rim into and out of the large lagoon-like area within the rim of the Banks, and with storm waves dragging bottom on the shoal rim, to produce the observed pattern. Of these agencies, the current action seems to be dominant in the area shown on the northern half of the map (Fig. 8) and in photographs (Figs. 2 and 3).

A somewhat different pattern, interpreted as being due mainly to waves building bars entirely under water, is that near the southeastern margin of the Banks, portrayed in part in Figures 7 and 9, and shown in greater extent on another photograph adjoining that of Figure 7 but not here reproduced. This pattern is distinctly linear, though some of the units are slightly *en échelon*.

The question arises as to whether the sand patterns here described are products of presently acting processes or have been inherited from earlier times when sea-level relations were different. The entire area of the Banks along the line of flight must have been out of water during the glacial epochs. At that time it seems possible that the giant ripple pattern shown in Figure 6 may have originated as wind-blown sand hills which may have been subdued in form but not entirely destroyed when the Banks were re-submerged following the melting of the glacial ice. The slightly elevated shoal rim bordering the Banks would have protected this central area from strong wave action during submergence.

At a certain stage in the submergence one would expect that shore bars would have formed along the shoal rim of the Banks. The relatively continuous bar revealed in Figure 8 a little over a mile east of the edge of deep water may be a modified remnant of such a feature.

But the anastomosing patterns covering a relatively large area as shown in Figure 8 and in Figure 2 could not, it seems, have been produced by the formation of successive shore bars as the Banks were submerged because, had they been so formed they should be more linear and should trend nearly parallel with the edge of the deep water instead of diagonally to it as they actually do, and those bars first formed would have been destroyed during the adjustment of the profile of

equilibrium as the inner, later (more easterly) bars were being formed. Besides, the water over the whole area is so shallow that storm waves must continually agitate the bottom so that any patterns now visible must be considered as products of presently acting processes.

As to the differences in scale between the sand accumulations in the Bahamas and those of the Clinton in Ohio, it seems possible, if not probable, that depth of water may have been the controlling factor. The Bahama area in question is too shallow to be exposed to the full velocity of the Gulf Stream current. In deeper water, exposed to a relatively strong ocean current, perhaps the scale of current-produced sand accumulations would be larger. That question can not be answered on the basis of the evidence here available.

Though perhaps none of the problems raised by the phenomena here portrayed has been solved, it is hoped that this glimpse of sand patterns forming beneath the water may throw new light on the nature and origin of subaqueous sand accumulations producing the lenticular sand bodies in which some oil and gas accumulations have been trapped.

PETERSBURG OIL POOL, HALE COUNTY, TEXAS¹

R. W. MALLORY²

Amarillo, Texas

ABSTRACT

The Petersburg pool is in southeast Hale County, near the southern boundary of the Texas Panhandle. The one-well pool was discovered by the Stanolind Oil and Gas Company in 1947 as a result of seismograph work. The discovery well, the Stanolind's Fisher No. 1, located 1,210 feet from the south and 660 feet from the west line of Sec. 5, Block CL, EL&RR Survey, was completed in limestone of Cisco age at total depth 6,992 feet, initially producing 1,008 barrels of oil in 18 hours. Within a year after completion of the Fisher No. 1, dry holes had been drilled on four sides, a granite test had disproved deeper possibilities, and the discovery well had begun to produce water. Oil accumulation in the Petersburg pool is due to local presence of a porous limestone reservoir in an area of anticlinal closure.

INTRODUCTION

The Petersburg pool is a one-well oil pool in Sec. 5, Block CL, EL&RR Survey, 6 miles west of Petersburg in Hale County, Texas. The discovery well, the Stanolind Oil and Gas Company's Fisher No. 1, located 1,210 feet from the south and 660 feet from the west line of Sec. 5, was completed in January, 1947, at the total depth 6,992 feet in limestone of the Cisco series. Figure 1 is an index map showing location of the Petersburg pool.

The problems involved in the search for and development of additional reef pools of this type are suggested by the four dry holes that have been drilled around the Fisher No. 1 and by the fact that the discovery well has begun to produce water in the first year of its production history.

EXPLORATION

The Stanolind Oil and Gas Company assembled a block of leases covering the Petersburg pool in 1938 after working the area by reflection seismograph. After discovery of the Anton and Irish pools 25 miles farther west as a result of seismograph work, the Stanolind reshot the Petersburg area and spudded the Fisher No. 1 in October, 1946. The shooting work indicated a local anticlinal structure with considerable closure, and development has verified the presence of such structure. There was no indication prior to development that the pool was of such limited extent.

DEVELOPMENT AND PRODUCTION

The Stanolind's Fisher No. 1, only producing well drilled to date, encountered the top of a limestone of Cisco age at 6,881 feet and was drilled to the total depth

¹ Manuscript received, March 12, 1948.

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² District geologist, Stanolind Oil and Gas Company. The writer is indebted to Peter Damm, Stanolind Oil and Gas Company, for sample examinations, to R. B. Hollingsworth, Midland, Texas, for paleontological determinations, and to W. T. Goodson, Jr., Stanolind Oil and Gas Company, for drafting work.

of 6,992 feet. Seven-inch casing was cemented at 6,890 feet and the pay section was acidized with 2,500 gallons. The well flowed 1,008 barrels of 39° gravity, paraffine-base oil in 18 hours on official potential test in January, 1947.

The well was assigned an allowable of 140 barrels per day and was produced at that rate for 8 months. In July the well started producing water and the proportion of water increased steadily during the remainder of the year in spite of

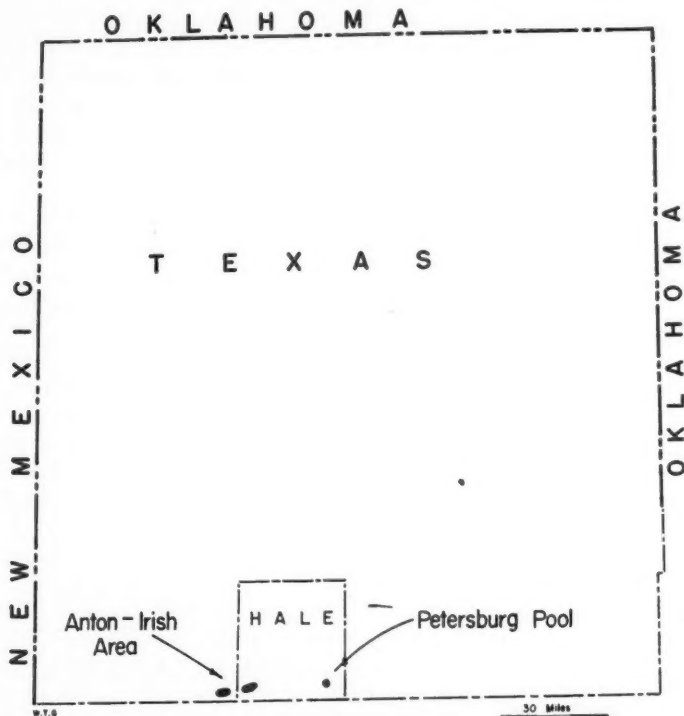


FIG. 1.—Index map of Panhandle district, Texas, showing location of Petersburg pool.

the use of smaller chokes. Monthly oil production declined rapidly and in January, 1948, daily average production was down to 58 barrels. On a 24-hour test in January, 1948, the Fisher No. 1 flowed 80 barrels of oil and 13.6 barrels of water on 11/64-inch choke with estimated gas-oil ratio of 432. Total production to February 1, 1948, was 40,609 barrels.

No other showings of oil or gas were encountered in the Fisher No. 1. A drill-stem test from 5,348 to 5,512 feet of porous zone in the Wolfcamp resulted in recovery of 3,065 feet of sulphur water.

The Stanolind's Lafont No. 1, 2,400 feet southeast of the discovery well, was the second well drilled. It encountered a somewhat thicker section than the Fisher No. 1 and was structurally lower on all markers. Top of the limestone was found at 7,105 feet but no showings were encountered while drilling and coring to the total depth of 7,344 feet. A drill-stem test from 7,126 to 7,175 feet recovered 4,920 feet of salt water in 2 hours. Completion of this dry hole revealed the fact that the upper part of the producing limestone in the Fisher No. 1 was represented by shale in the Lafont No. 1.

The Stanolind's Hale County State Bank No. 1, on the opposite side of the structure from the Lafont No. 1, was found very similar in structural position and stratigraphy to the latter well. The Fisher producing zone was apparently represented by about 25 feet of limestone from 7,390 to 7,415 feet. A 30-minute drill-stem test from 7,390 to 7,528, total depth, recovered only 90 feet of drilling mud and the well was abandoned.

The Standard of Texas-Humble's Hunt No. 1, located 1,500 feet west of the Fisher No. 1, also was lower than that well on structural markers and drilled a thicker section. The top of the limestone was encountered at 7,155 feet and, after a one-hour drill-stem test from 7,175 to 7,224 feet recovered only 810 feet of muddy salt water, the well was plugged at the total depth of 7,224 feet.

In the summer of 1947 the Stanolind drilled its Fisher No. 2, located 1,700 feet northeast of the pool-opener and on top of the seismograph structure. As in the three previous failures, this test was found structurally lower than the Fisher No. 1. The limestone was topped at 7,095 feet and when it was proved barren, drilling was continued to basement rock. The Fisher No. 2 was abandoned at the total depth of 8,394 feet in rhyolite porphyry without encountering any evidence of deeper pay zones.

STRATIGRAPHY

In spite of the number of dry holes that have been drilled along the Matador arch, much confusion exists regarding correlations and nomenclature in the area. Some clarification has been provided from drilling in the Petersburg pool but many of the time divisions must necessarily remain tentative. Figure 2 is a graphic and Schlumberger log of the Stanolind's Fisher No. 2.

TERTIARY

Four hundred feet of Tertiary sand, gravel, and caliche underlie the nearly flat surface of the Petersburg area. The beds are of economic value in that they supply irrigation water for farms of the area.

TRIASSIC

Triassic beds of the Dockum group occur between the base of the Tertiary and a depth of 1,050 feet. The beds are composed chiefly of red and gray shale with 50 feet of gray, coarse sandstone and conglomerate at the base.

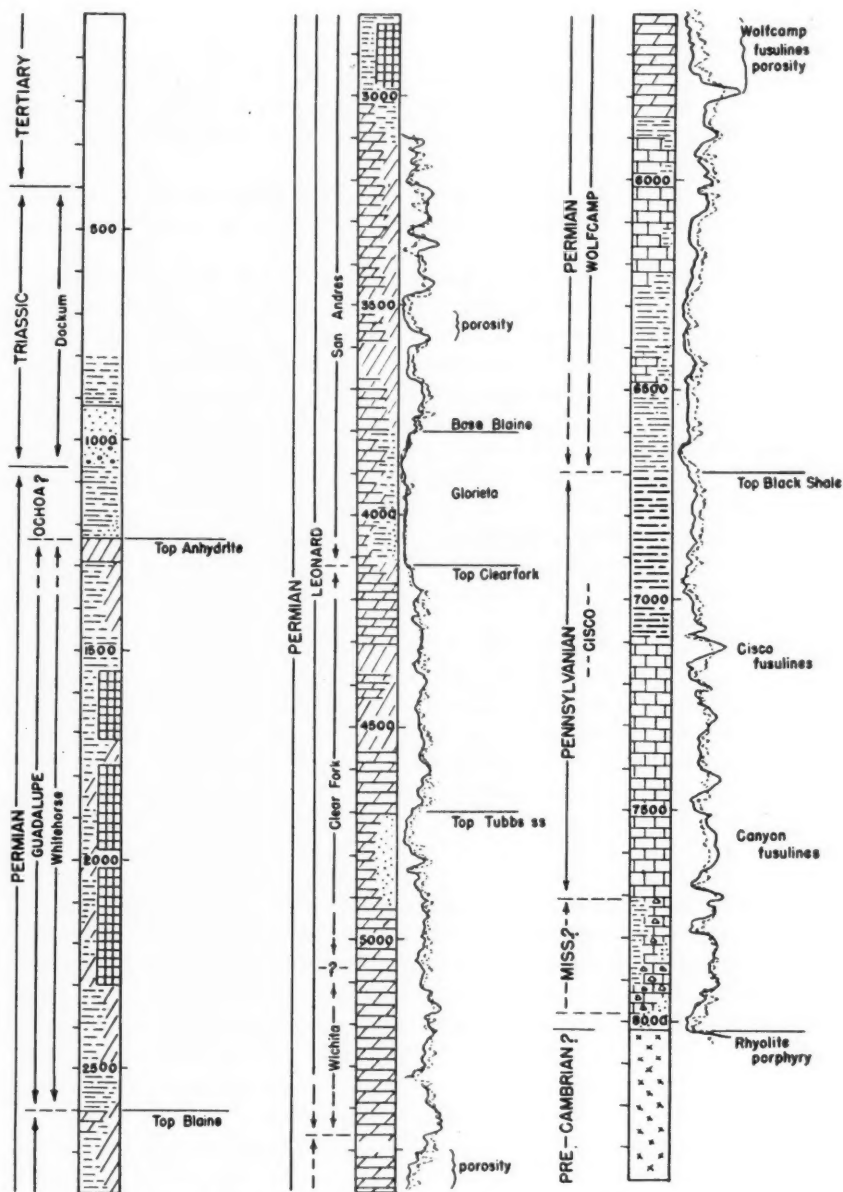


FIG. 2.—Columnar section and Schlumberger log of Stanolind's Fisher No. 2.

PERMIAN

Approximately 5,600 feet of Permian strata are present, with the exact Permian-Pennsylvanian contact not yet determined. The Permian section thickens off-structure as shown in Figure 5B, an isopach map of Permian section from top of anhydrite to top of black shale. The rate of thickening increases with depth, most of it occurring in the lowermost 550 feet of the Permian.

Ochoa series.—Two hundred feet of red shale underlying the Triassic conglomerate is here tentatively assigned to the Ochoa series because of its stratigraphic position.

Guadalupe series.—The Whitehorse group consists of approximately 1,350 feet of red and maroon shale and white anhydrite. Traces of gray, fine- to medium-grained sandstone are present and salt casts occur in the anhydrite in the lower part of the section. The first anhydrite encountered makes a distinctive sample and electric-log marker which is used as the top of the Whitehorse group.

Leonard series.—The San Andres group is 1,500 feet thick and has been subdivided into the Blaine and Glorieta members. The Blaine consists of red shale, salt, anhydrite and dolomite, with red shale and salt predominating in the upper part of the section and anhydrite and tan dolomite in the lower part.

The Glorieta member comprises 300 feet of section underlying the Blaine. It is similar to the Blaine except for presence of small amounts of light gray, fine-grained sand. The base of the San Andres marks the base of the Permian red-shale section.

Approximately 900 feet of gray to tan finely granular dolomite and white to light tan anhydrite are assigned to the Clearfork group of which neither top nor base can be recognized with certainty. The best Permian marker in the area, the Tubbs sandstone, occurs about 600 feet below the top of the Clearfork. It is gray, fine-grained sand and is a distinctive sample and electric-log point.

Wolfcamp series.—Below the Tubbs sandstone is a 950-foot interval composed entirely of gray and tan dolomite having a finely crystalline texture. This interval is considered to include the lower part of the Clearfork and the lowermost Wichita group of the Leonard series as well as the upper part of the Wolfcamp. The top of the Wolfcamp is placed at the top of a porous dolomite from 5,500 to 4,800 feet which is approximately equivalent to the Brown dolomite of the Panhandle field. Wolfcamp fusulines were found at 5,560–5,570 feet in the Fisher No. 1. Underlying the porous dolomite is an 800-foot section of gray, oölitic limestone and gray, soft, calcareous shale which is also assigned to the Wolfcamp series. The upper 400 feet of this interval is largely composed of limestone while the lower half is mostly shale.

PENNSYLVANIAN

Strata from 6,670 to 7,690 feet in the Fisher No. 2 are here assigned to the Pennsylvanian although it is possible that both top and base should be lowered approximately 300 feet. The top of the Pennsylvanian has been placed at the

top of a black, carbonaceous shale which is a distinct lithologic change from the overlying gray shales and limestones. Three hundred twenty-four feet of black shale containing some thin beds of brown, chalky limestone were present in the Fisher No. 1 directly above the producing limestone.

The producing zone in the Fisher No. 1 is 111 feet of light gray, highly fossilif-

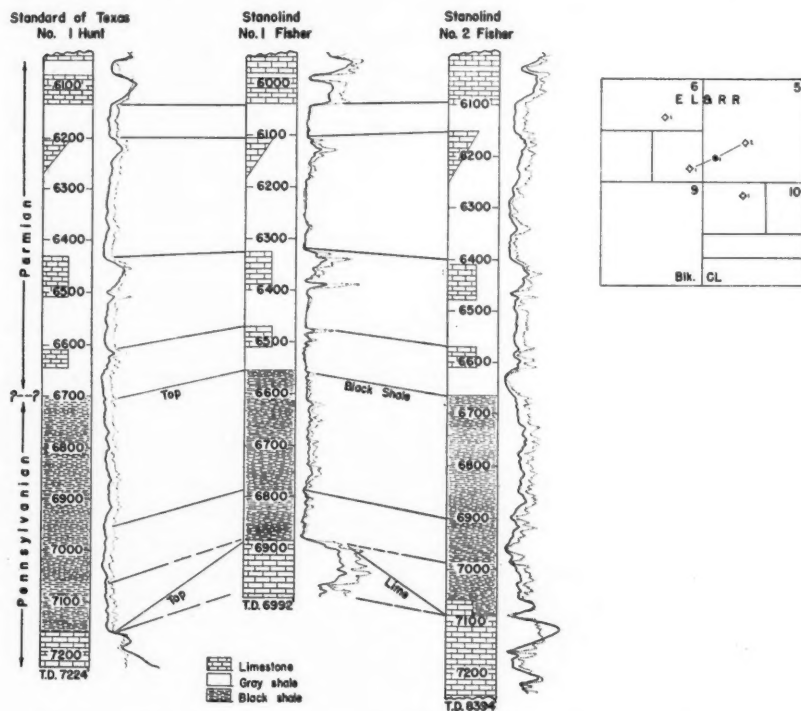


FIG. 3.—Schlumberger cross section of Petersburg pool. Datum, base of limestone section.

erous, chalky to finely crystalline limestone. Poor core recovery through the section made it impossible to determine the amount of effective "pay." The zone has been correlated with the Thrifty group of the Cisco series on the basis of paleontological evidence.

In the four dry holes surrounding the discovery well the upper part of the limestone was missing and instead additional black shale was drilled, thus proving a very limited areal extent for the productive zone. Figure 3 is a cross section of the Petersburg pool showing the limestone-black shale relationship and the thickening off-structure of both Permian and Pennsylvanian strata.

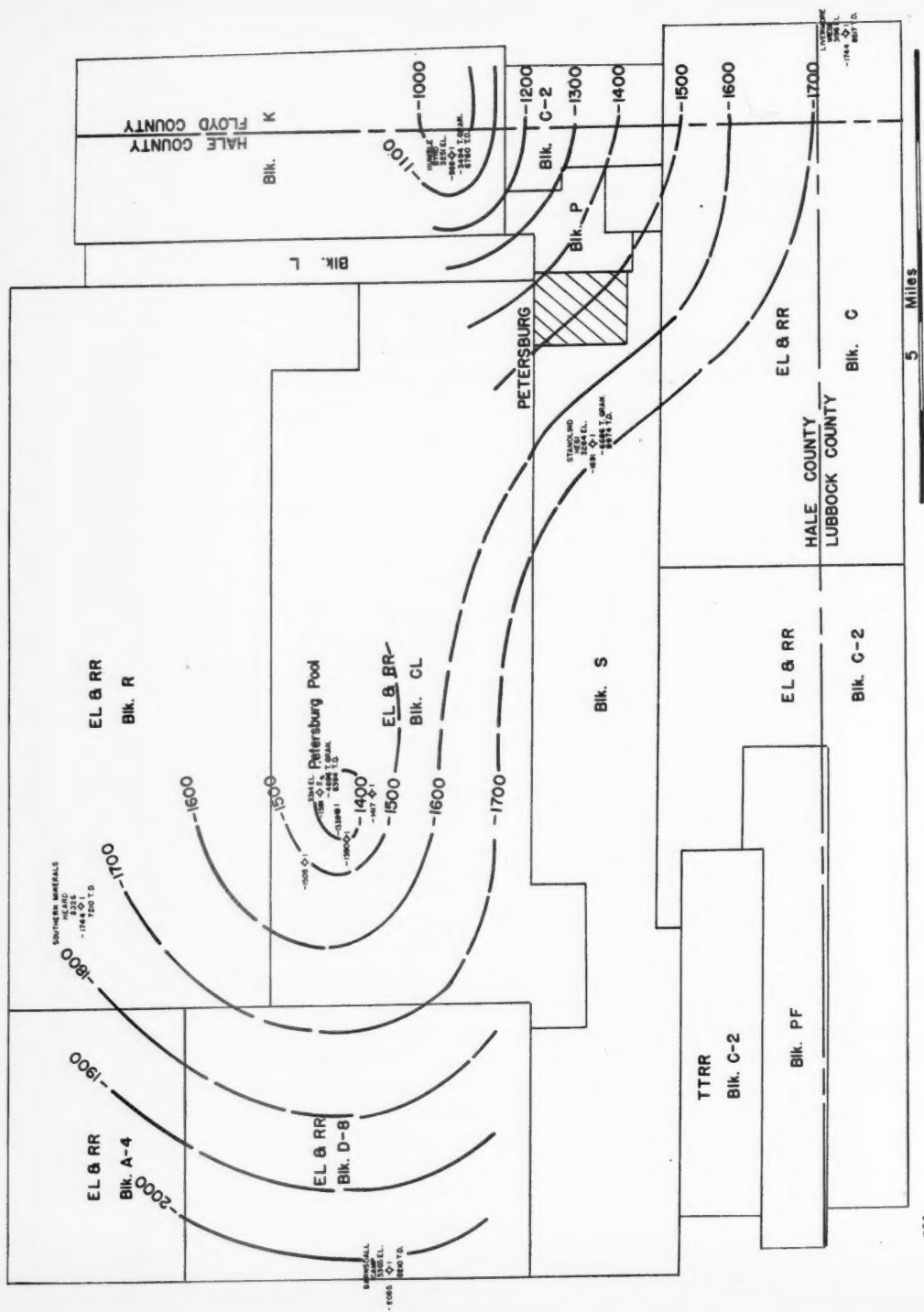


FIG. 4.—Structure map of southeast Hale County, contoured on top of Tubbs sandstone.

It is evident from Figure 3 that the productive limestone in the Fisher No. 1 was present prior to deposition of the surrounding black shale. Though not conclusive evidence, this fact is indicative of reef origin for the limestone. The poor stratification shown in cores and the highly fossiliferous and in part chalky character of the limestone also support such a theory.

Below the black shale, the Fisher No. 2 drilled 600 feet of light gray to tan, shaly and finely crystalline limestone to a depth of 7,690 feet. The strata are unquestionably Pennsylvanian in age but no attempt has been made to subdivide the zone. The interval is fossiliferous in part, and *Triticites* resembling Canyon types were found between 7,580 and 7,600 feet.

MISSISSIPPIAN (?)

The top of the Mississippian is tentatively placed at the top of the first chert at 7,690 feet, chiefly on the basis of regional correlations. Three hundred feet of gray, crystalline, cherty limestone are present with the amount of chert showing a marked increase at 7,840 feet. Below the cherty limestone is a 20-foot gray, coarse, glauconitic sandstone which contains some fragments of the underlying igneous rock. The sandstone may be Cambrian in age.

Although the possibility exists that this section may be lower Pennsylvanian, the writer at present considers that it represents lowermost Mississippian and that pre-Canyon Pennsylvanian beds are not present in the Fisher No. 2.

PRE-CAMBRIAN (?)

At 8,010 feet the Fisher No. 2 drilled into dark red-brown rhyolite porphyry containing jasper and feldspar phenocrysts in a very fine-grained matrix. Flow structure and banding are visible in core specimens. Because of the extrusive nature of the rock, drilling was continued to the total depth of 8,394 feet before abandonment, in the hope of penetrating the igneous mass and encountering additional sedimentary section below.

STRUCTURE

REGIONAL STRUCTURE

An east-west trending high structure in southern Hale, Floyd, Motley, and Cottle counties is located between the main Permian basin of West Texas and the shallower Palo Duro basin of the Texas Panhandle. The feature has been referred to as the westward extension of the Red River arch, westward extension of the Electra arch, and as the Matador arch. Because the feature actually underlies a part of the Matador Ranch in Motley County, the last term is here used.

The trend has been extensively explored for oil but with generally disappointing results until discovery of the Anton pool in Lamb County in 1944 and the Irish pool in Hale County in 1946. Both fields have structural closure and produce from Permian dolomites. Other subsurface highs along the Matador arch have been tested to basement rock, with little or no indications of oil or gas.

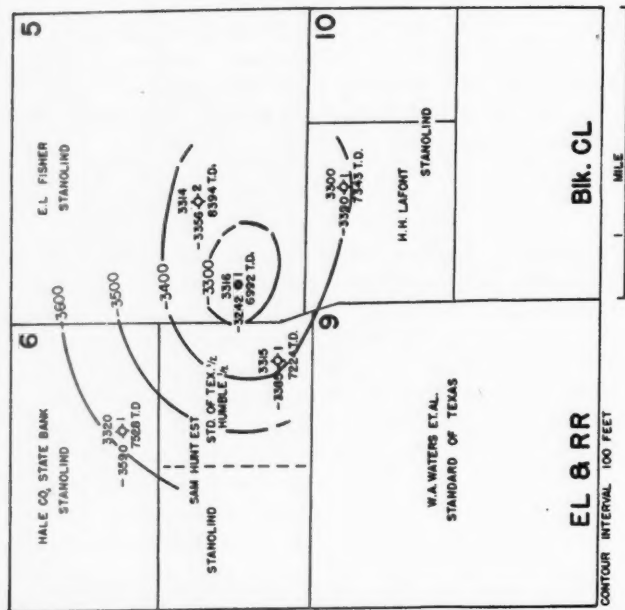
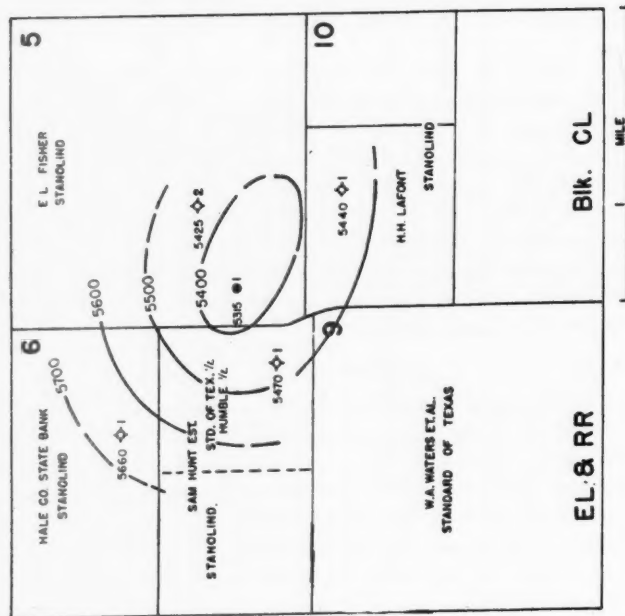


FIG. 5 (A)—Structure map of Petersburg pool, contoured on top of black shale.



(B) Isopach map, showing thickness of Permian section from top of anhydrite to top of black shale.

Figure 4 is a structure map of southeast Hale County, contoured on the top of the Tubbs sandstone. It illustrates several features found over a much wider area along the Matador arch. The arch is a definite westward-plunging anticline with a steeper dip indicated on the south side than on the north (in Lamb and Hale counties faulting of considerable magnitude with downthrow on the south may be present). The sea-level elevation of the top of the basement rock varies greatly over small distances but rises in general toward the east. Granite "highs" underlie structural "highs."

LOCAL STRUCTURE

Figure 5A is a structure map of the Petersburg pool contoured on the top of the black shale, approximately 350 feet above the productive limestone. The pool occupies a small area of closure on the axis of the Matador arch. The amount of structural relief increases with depth as shown by the following amounts of closing (northeast) dip between the Fisher No. 1 and Fisher No. 2 on successively deeper beds: top anhydrite, 7 feet; base Blaine, 20 feet; top Tubbs sandstone, 42 feet; top black shale, 115 feet. The top of the Cisco limestone shows even more relief, as shown in Figure 3, but it is not a true stratigraphic horizon. There is no evidence of faulting.

The last major uplift of the Matador arch is believed to have occurred in early Pennsylvanian time. The writer considers that much of the regional and local structure apparent in Permian and Pennsylvanian beds is due to compaction of sediments over the irregular surface upon which they were deposited. In the Petersburg area some of the uneven compaction is probably attributable to presence of the limestone reef. Formation of the reef itself is undoubtedly related to pre-Cisco structural or topographic relief.

TYPE OF ACCUMULATION

Oil accumulation in the Petersburg pool is due to local presence of a porous limestone reservoir and to presence of anticlinal structure. Source of the oil may have been either the limestone in which it is found or the black shales surrounding and overlying the reservoir beds.

The primary importance of the Petersburg discovery is that it is a reef-type accumulation. While in this case the pool is closely linked to regional and local structure and was discovered for that reason, it is believed that other Pennsylvanian reef production, not necessarily connected with prominent structure, will be found in the general area.

SUBMARINE GEOLOGY OF RANGER BANK, MEXICO¹

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ABSTRACT

A large collection of bottom samples and underwater photographs from the top of a 67-fathom flat-topped bank off Baja California, Mexico, was studied. The data indicate that wave action bevelled Jurassic (?) metamorphic and Miocene (?) volcanic and sedimentary rocks during a time of greater relative emergence. After submergence of the bank or rise of sea-level, the top of the bank was partly veneered by glauconite and organic sediments composed of Foraminifera and small pieces of mollusks. Abundant phosphorite pebbles on the surface may be derived from underlying Miocene strata. The loose sediments found on the bank are completely unlike those of the truncated rocks and are also different from the muds of surrounding deeper areas.

INTRODUCTION

During the war a large amount of information regarding the composition and topography of several small areas of the sea floor was obtained in the course of submarine acoustical research by the Navy. One of the areas investigated was Ranger Bank, which lies about 260 miles south-southeast of San Diego. This bank has been fished for many years and is well known to commercial tuna fishermen.

The United States Navy Hydrographic Office chart No. 2324, printed in 1875, shows only a few soundings and bottom notations on Ranger Bank. A later and larger-scale chart, No. 1193, made by U. S. S. *Ranger* between 1887 and 1890, contains 18 soundings and 9 bottom-material notations for the top of the bank. The bottom notations on both charts are based only on minute samples and scratches on tallowed sounding leads. On two visits during 1939 and 1941 the *Velero III*, a University of Southern California research ship, made four dredgings, all on the north half of Ranger Bank. Each of the dredgings recovered rock (8). The Navy collections were made by the writer from the *E. W. Scripps*, a marine research ship which was operated during the war by the University of California Division of War Research at the United States Navy Radio and Sound Laboratory, San Diego. The field study of the bank was completed in one day, May 19, 1944. During this day 19 bottom samples, 9 bottom photographs, and a few temperature-depth records were obtained.

The study of the samples and other data is of interest because only a few such banks have been sampled. Some of these, like Agulhas Bank, have been described,

¹ Manuscript received, December 31, 1947.

² University of Southern California. This article is based on work performed for the Bureau of Ships under Contract Nobs-2074 (formerly OEMsr-30) with the University of California Division of War Research. Preliminary plotting and filing of the samples was done at the University of California Division of War Research. Final studies, made at the University of Southern California, were aided by a research grant from Allan Hancock Foundation. Appreciation is gratefully acknowledged to H. R. Gould, who made most of the mechanical analyses; to M. L. Natland, who identified the Foraminifera in the sediments and the phosphorite; to Remington Kellogg, who identified the vertebrate bones; and to K. E. Lohman, who identified the diatoms in a mudstone.

but only from the viewpoint of the glauconite or phosphorite nodules found on them (2, 11). Others, like those off southern California, have been briefly mentioned in discussions of regional physiography or regional sediments (14). As far as the writer is aware, no comprehensive description of such banks as units is available. Knowledge of conditions operating on existing banks should help in making proper interpretations of similar ancient environments encountered in oil-drilling operations.

GEOLOGICAL ENVIRONMENT

On the Baja California peninsula southeast of Ranger Bank there is a northwesterly trending mountain range, Sierra Vizcaino, which is slightly oblique to the coast. It separates the low terraced areas bordering the Pacific Ocean on the west from the broad flat lowland at the head of Vizcaino Bay. At the coast the range projects outward to form Point Eugenia (Fig. 1). Cedros Island and Ranger Bank are beyond Point Eugenia and are directly in line with the mountain range; therefore, they may constitute a submarine extension of it.

Because of their physiographic relationships Ranger Bank might be expected to have rocks similar to those of Cedros Island. On the basis of brief observations, Hanna (10), reported the presence of Jurassic rocks, including "Franciscan" chert, sandstone, conglomerate, and schist on Cedros Island and on the San Benito Islands. On Cedros Island he also found Cretaceous shale, Miocene and Pliocene sedimentary rocks, and some volcanics. Anderson (17), after reviewing the scanty literature, indicated the presence of undivided Jurassic-Triassic rocks and Cretaceous intrusives on Cedros Island.

Some similarity in late geological history of Cedros Island and Sierra Vizcaino is suggested by the flora of the region. According to H.S. Gentry (personal communication), the flora of Sierra Vizcaino is similar to that of Cedros Island, which is now separated from the peninsula by a water barrier, but it is different from the flora of the mountain range which is parallel with, and 30 miles east of, Sierra Vizcaino on the peninsula, even though both ranges are connected by land.

TOPOGRAPHY

The topography of Ranger Bank is shown by Figure 1 which is based on soundings shown on H. O. chart No. 1193, supplemented by others taken by the *Velero III* and the *E. W. Scripps*. Little confidence should be placed on details of the contours because only about 30 good soundings are available for the top of the bank, and the surrounding deeper areas are even less densely sounded. The soundings and the contours based on them, however, are reliable enough to show that the bank is fairly flat-topped with a gentle slope from the shallowest depth of 67 fathoms to the edge, which lies at 75-80 fathoms. Below this break the slope increases abruptly so that the sides of the bank reach a steepness of about 10°. The flat top is elongate north and south and it has a length of 11 and a maximum width of 4 statute miles. Toward the south end the bank tapers to a width of only

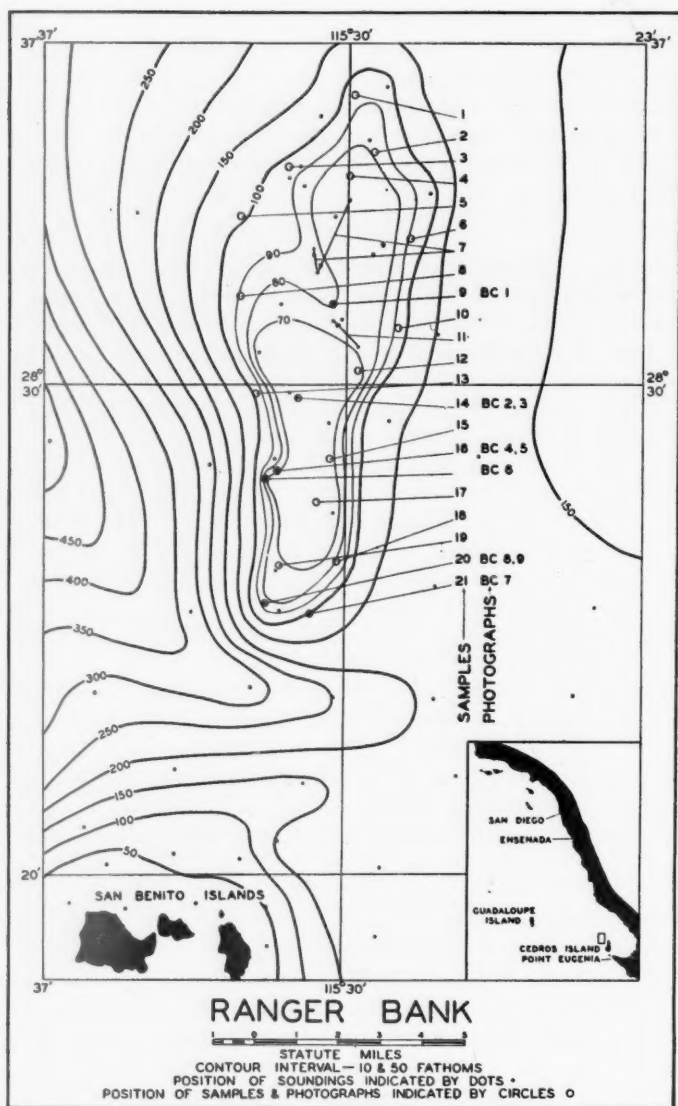


FIG. 1.—Topography and positions of samples and underwater photographs, Ranger Bank, Mexico.



FIG. 2.—Underwater photograph (BC 1) at 82 fathoms, showing angular blocks and rounded cobbles partly covered by encrusting organisms. Note fish above and right of center. Area is approximately 9 square feet.

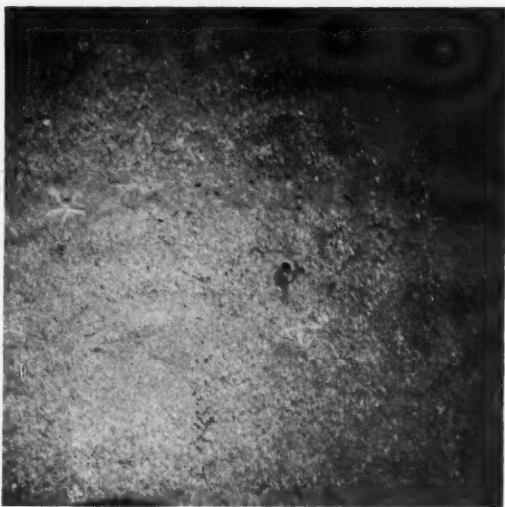


FIG. 3.—Underwater photograph (BC 4) at 70 fathoms, showing foraminiferal glauconitic sand having faint oscillation ripple marks. Note two starfish. Area is approximately 9 square feet.

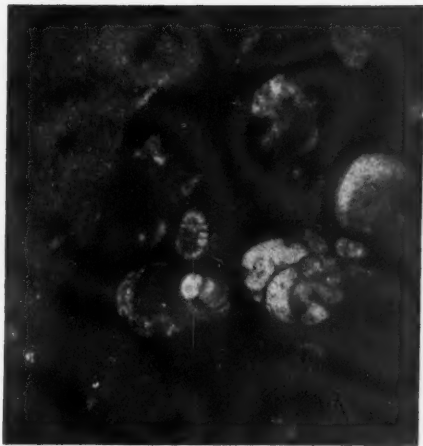


FIG. 5.—Typical polished section of phosphorite from sample 11. Note presence of accretionary layers, mineral grains, and Foraminifera. $\times 10$.



FIG. 6.—Phosphatized bone fragments associated with phosphorite of samples 7 and 11. $\times \frac{1}{2}$.

FIG. 8.—Typical untreated fine-grained sand (sample 4), showing Foraminifera, shell fragments, and mineral grains. $\times 10$.

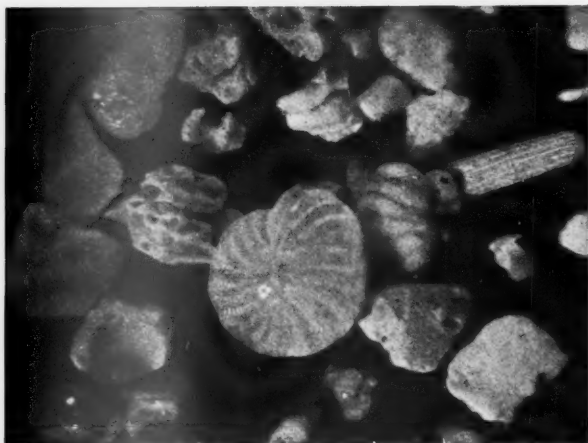


FIG. 9.—Typical untreated coarse-grained sand (sample 18), showing large Foraminifera, shell fragments, echinoid spines, and bryozoans. $\times 10$.

FIG. 10.—Coarse light insoluble residue of sample 1, showing typical abundance of glauconitic internal casts of Foraminifera. Detrital mineral grains, sponge spicules, and coprolites are also present. $\times 10$.



1½ miles. Ranger Bank resembles the deeper but much better sounded Northeast Bank off southern California (16).

East and north of Ranger Bank is the broad Vizcaino Bay, the muddy floor of which lies at about 150 fathoms depth near the bank. On the south the bank is separated from the near-by San Benito Islands by a 300-fathom trough. West of the bank the depths gradually increase to about 2,500 fathoms at the bottom of the continental slope.

OCEANOGRAPHY

The oceanic currents over Ranger Bank have not been studied, but observations at three oceanographic survey stations near Cedros Island occupied by the *E. W. Scripps* during July, 1939 (18), reveal the presence of a southward drift a few miles west of the bank. This drift is an extension of the California Current.

As the bank is in a very exposed position, the waves are generally fairly high, and at the time of the sampling cruise the wave height was about 7 feet. Four continuous temperature-depth recordings over the bank were made with a bathythermograph (7). Each record shows a layer of uniform temperature of 16°C., extending from the surface to 30 fathoms, testifying to the turbulence of the upper water. After winter storms this mixed layer is doubtless much thicker.

BOTTOM PHOTOGRAPHS

Nine bottom photographs were taken with an under-water camera (6) on the bank at depths between 67 and 104 fathoms. For each photograph the camera was set about 6 feet above the bottom and a small flash bulb provided the necessary light. The area covered in each picture is about 3 by 3 feet. As shown by Table I only two of the photographs reveal rocky bottom and in both of these areas the rocks were partly covered by encrusting organisms, mostly algae, bryozoans, and hydroids (Fig. 2). Most of the photographs show sandy sediment on which there lay a few starfish and fragments of algae. Sand in two and possibly three of the photographs at depths of about 70 fathoms has gentle oscillation-type ripple marks with a wave length of about 3 inches and an amplitude of probably less than ½ inch (Fig. 3). The presence of the ripple marks supports the evidence of the mixed water layer in showing the great depth of wave motion.

BOTTOM SAMPLES

GENERAL

During the visit to Ranger Bank by the *E. W. Scripps*, 19 bottom samples were obtained with a snapper. The samples range in weight from 2 to 850 grams (Table I). Ten of the samples weigh 100 grams or more, and all excepting one of these large samples consist of sand. The large size of the sand samples apparently resulted from the ease with which the snapper jaws could bury themselves in the bottom before closing. The rock samples are of loose pebbles scraped from the bottom or chips broken from large masses; consequently, most are smaller than the sand samples.

On the visits of *Velero III* bottom samples for biological studies were obtained with a large dredge. One sample, Hancock No. 1011, was destroyed; two others, Hancock 1246-D1 and 1246-D2 were mixed and form sample 7; a fourth, Hancock 1247, is sample 11. These two samples are especially valuable because they are much larger than the snapper samples and contain many rock fragments.

The position of each available bottom sample is indicated in Figure 1. The samples and photographs are also listed in Table I with latitude, longitude, and depth. As shown by this table, the 21 samples range in weight from 2 grams to 2 kilograms. Nine samples consist only of sand, 6 only of rock or gravel, and the remaining 6 samples contain sand plus either rock or gravel.

ROCK

Rock fragments were recovered in 12 of the samples from Ranger Bank. None of the fragments is larger than 10 centimeters in diameter, nor is any of them

TABLE I
RANGER BANK SAMPLES—GENERAL INFORMATION

Sample Number	Field Number	Depth (Fathoms)	Lat. (N)	Long. (W)	Sample Weight (Grams)	Per Cent Rock	Per Cent Sand	Bottom Notation
1	N 1,951	95?	28°35.9'	115°29.8'	650	5	95	SG
2	N 1,953	82?	34.7'	29.4'	500	0	100	S
3	N 1,948	90?	34.4'	31.4'	5	50	50	RS
4	N 1,952	77?	34.2'	30.0'	850	0	100	S
5	N 1,949	102?	33.4'	32.5'	100	40	60	SG
6	N 1,954	91?	33.0'	28.5'	2	0	100	S
7	H 1,246-D1	78-81	33.7'	30.0'	1,350	97	3	RS
	H 1,246-D2	81-83	32.3'	30.7'				
			32.8'	30.7'				
8	N 1,950	89?	31.8'	32.5'	750	0	100	S
9	N 1,956	82	31.6'	30.3'	15	95	5	GS
10	N 1,955	92?	31.2'	28.8'	300?	100	0	R
11	H 1,247	76-77	30.7'	29.7'	2,000	100	0	R
			31.3'	30.3'				
12	N 1,950	69?	30.3'	29.7'	125	0	100	S
13	N 1,957	98?	29.8'	32.1'	200	0	100	S
14	N 1,958	68	29.7'	31.1'	75	100	0	G
15	N 1,961	68?	28.5'	30.4'	50+	100	0	R
16	N 1,962	70	28.3'	31.6'	30+	0	100	S
17	N 1,960	68?	27.7'	30.7'	50	100	0	R
18	N 1,965	81?	26.5'	30.2'	600	0	100	S
19	N 1,964	71?	26.3'	31.6'	15	90	10	RS
20	N 1,967	85	25.6'	31.0'	10	100	0	R
21	N 1,966	104	25.3'	30.8'	100	0	100	S
BC 1	BC 1	82	28°31.6'	115°30.3'		100	0	RG
BC 2	BC 2	67	29.7'	31.1'		95	5	RGS
BC 3	BC 3	70	29.7'	31.1'		0	100	S
BC 4	BC 4	70	28.3'	31.6'		0	100	S
BC 5	BC 5	71	28.3'	31.6'		0	100	S
BC 6	BC 6	70	28.1'	31.9'		0	100	S
BC 7	BC 7	104	25.3'	30.8'		0	100	S
BC 8	BC 8	85	25.6'	31.0'		0	100	S
BC 9	BC 9	85	25.6'	31.0'		0	100	S

definitely broken from submarine outcrops. About half of the samples containing rock also have more or less associated sand. As shown by Table II, most of the rock samples contain fewer than 40 pieces; however, the two samples taken in dredges, samples 7 and 11, have 518 and 838 pieces of rock, respectively. Altogether, about 1,600 pieces larger than 4 mm. diameter were examined. Identifi-

cations were based largely on polished sections and on oil immersion studies. No claim is made for great accuracy, because of the uncertainties inherent in the identification of such small and varied fragments.

The most abundant kind of rock is phosphorite, which was found in half of the samples, ordinarily predominating over other kinds of rock. It is noteworthy that in the two large dredged samples, the phosphorite has approximately the same

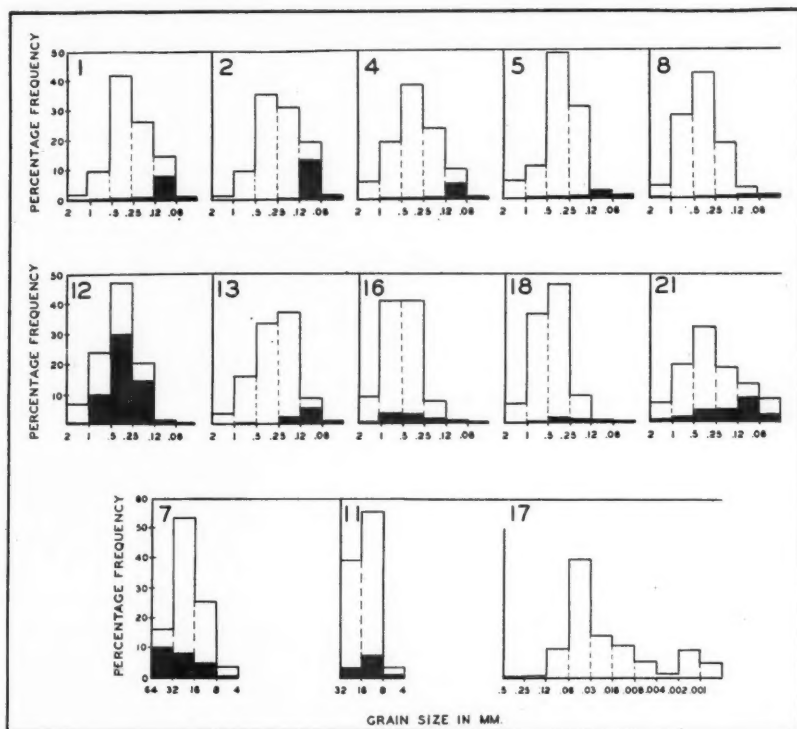


FIG. 4.—Histograms showing size distribution of samples from Ranger Bank.
Sand—samples 1, 2, 4, 5, 8, 12, 13, 16, 18, 21. Black part is insoluble residue.
Rocks—samples 7, 11. White part is phosphorite.
Mudstone—sample 17.

size distribution as the non-phosphatic rocks (Fig. 4). Its lithologic character is like that of other phosphorite from off southern California (4) in its light to dark brown color, shiny nodular surface, manganese oxide staining, discontinuous layers of accretion, and inclusion of rock fragments, glauconite, coprolites, bone fragments, shells, and Foraminifera. Figure 5 is a polished section of the phos-

phorite containing an exceptional abundance of Foraminifera. Other pieces of phosphorite contain a few poorly preserved tests. In the polished section partly shown in Figure 5, M. L. Natland identified *Valvulineria* (?), *Baggina* (?), and *Bolivina breviorum*, an assemblage which is characteristic of either Luisian or Relizian age, middle Miocene. Bones enclosed by, or associated with, the phosphorite were identified by Remington Kellogg and include a fragment of tympanic bulla of a fossil whale-bone whale, shark tooth, vertebra probably of a turtle, and a part of the skull of some reptile. Many other more fragmentary fish and mammal bones were also present. Some of the bones are shown in Figure 6.

TABLE II
ROCKS FROM RANGER BANK

Sample Number	Number of Pieces	Maximum Diameter (Centimeters)	Roundness	Rock Types and Percentage of Pieces
1	14	1	SA-SR	Phosphorite (100)
3	5	1	A-R	Siltstone (100)
5	41	2	A-SR	Phosphorite (78)
				Basalt (7)
				Andesite (5)
				Fine-grained igneous (5)
				Schist, hornblende (5)
7	518	5	A-R	Phosphorite (88)
				Rhyolite (6)
				Fine-grained igneous (6)
				Schist, glaucophane (<1)
9	30	1½	SR-R	Phosphorite (90)
				Rhyolite (7)
				Schist, augite (3)
10	1	10	R	Rhyolite (100)
11	838	3	A-R	Phosphorite (85)
				Andesite (5)
				Rhyolite (3)
				Fine-grained igneous (2)
				Metavolcanics (2)
				Sandstone (2)
				Schist, glaucophane (1)
14	1	5	SA	Phosphorite (100)
15	75	1	A-SA	Shale (100)
17	107	?		Mudstone, soft (100)
19	30	1½	A	Shale (100)
20	4	2	A	Mudstone (100)

Several of the samples contain sedimentary rocks other than phosphorite. The commonest of these rocks is a non-fossiliferous shale found mostly near the south end of the bank. Well cemented sandstone and siltstone, and a soft mudstone are also present. The mudstone (sample 17) contains abundant volcanic glass shards, Radiolaria, and pelagic Foraminifera. On fresh fractures it has a slight odor of petroleum and it yields an oil indication on treatment with acetone. As shown by the histograms of Figure 4, the mudstone is much finer-grained than any of the loose sands which mantle the bank. In its general characteristics it resembles the Miocene Malaga mudstone of the Los Angeles area; and on the basis of diatom content K. E. Lohman identified it as almost certainly upper Miocene.

Five of the rock samples are composed wholly or in part of igneous rock. Perhaps predominant is rhyolite containing much quartz. Andesite and basalt were also identified, but in addition there are a number of pieces of volcanics so fine-grained that they could not be classified. About 15 per cent of the pieces of

igneous rock are partly altered to serpentine, are brecciated, and contain quartz-filled cracks, probably as the result of hydrothermal action. No such alteration of any sedimentary rocks was found. The age of the volcanic rocks can not be determined with certainty, but probably they were formed during the Miocene, the time of most widespread vulcanism in southern California.

Metamorphic rocks, although not abundant, nevertheless are among the

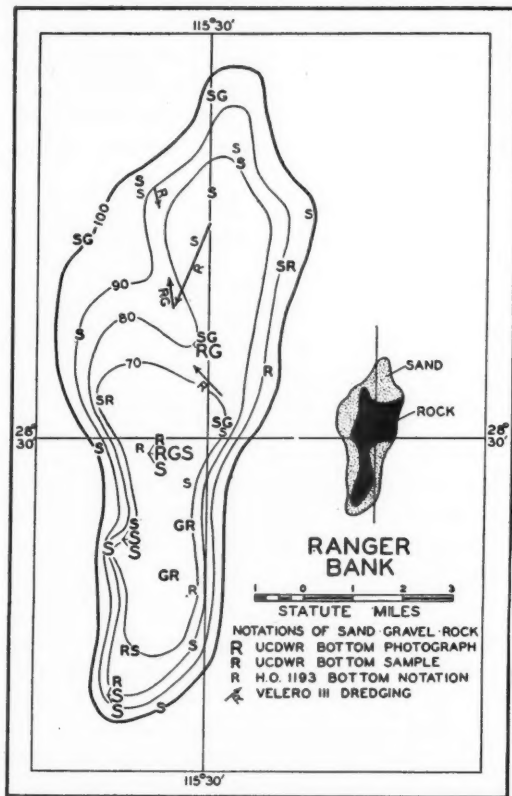


FIG. 7.—Composition of top of Ranger Bank based on samples, photographs, and navigational chart notations. Insert is generalized map of surface materials.

most interesting discoveries on the bank. A number of slightly metamorphosed igneous rocks, termed metavolcanics in Table II, are present. In addition, there are several pieces of clearly schistose rock, chief of which is glaucophane schist. This schist is very similar to some of those found on Catalina Island and reported as of Jurassic-Triassic (?) Franciscan age by Woodford (20). Schist of similar

composition is known from Los Coronados Islands off San Diego, where it occurs in a supposed Miocene San Onofre breccia. Large and small pieces have also been dredged from Sixtymile Bank, west of Los Coronados Islands, and from other places on the sea floor off southern California (5).

Comparison of Table II with Figures 1 and 7 reveals that rock was obtained along almost the entire length of Ranger Bank, but that in the northwest part of the bank the rock may be covered by a thin layer of sand. The sand is probably so thin that the weight of the dredge was sufficient to break through it and retrieve rock in areas where samples collected with other devices consist only of sand. Within the rock area igneous and metamorphic rocks came only from the north middle part of the bank. From the extreme north and south ends of the bank only sedimentary rocks were obtained. Phosphorite, enigmatical as usual, is associated with all kinds of rock.

TABLE III
SAND SAMPLES FROM RANGER BANK

Sample Number	Median Diameter (Millimeter)	Sorting Coefficient	Percentage Silt and Clay	Insoluble Residue				Percentage Heavy Insoluble Minerals
				Percentage Weight	Median Diameter (mm.)	Sorting Coefficient	Roundness	
1	0.270*	1.52*	1.24*	12.4	0.080	1.27	A-SA	0.5
2	0.235	1.63	1.73	15.0	0.078	1.21	A	0.4
3							A-R	trace
4	0.320*	1.60*	0.66*	8.2	0.073	1.33	A	0.3
5	0.305*	1.27*	0.27*	5.6	0.096	1.90	A-SR	0.5
6							A	trace
7	0.080	1.44	0.12	5.8	0.430	2.78	A-SA	trace
8	0.390	1.49	1.53	4.5	0.070	1.58	A	0.2
9							A	0.5
12	0.390	1.45	0.37	56.2	0.324	1.38	A-SA	2.2
13	0.265*	1.54*	0.45*	8.5	0.106	1.33	A	0.3
16	0.518	1.40	0.18	10.5	0.440	1.73	A-SA	0.8
18	0.460	1.38	0.10	4.1	0.260	1.55	A	0.4
19							A	0.4
21	0.310*	1.85*	7.67*	22.6	0.125	1.90	A-SR	1.5?

* Average of two analyses.

Although many of the rocks are partly rounded, they also support growths of encrusting organisms which could not remain attached if the host rock could be rolled around under present conditions. It seems probable, therefore, that the rocks attained their present shapes under past environmental conditions, perhaps during a time of greater emergence when the bank was being bevelled by wave erosion. While the rocks were becoming rounded, they must also have been transported some distance from their outcrops. This distance appears to be short; otherwise, the various types of rock would have been mixed instead of being more or less segregated into different zones as shown by the sampling.

SEDIMENTS

Grain size.—Nine samples from Ranger Bank consist exclusively of sand, and 6 other samples have some sand together with rock fragments. Of these 15 sediment samples, 11 were sufficiently large for mechanical analysis. The results of

the analyses are shown in Figure 4 and Table III. The median diameters of the whole sediment range between 0.235 and 0.980 mm. and average 0.414 mm. None of the sorting coefficients is higher than 1.85; therefore, all fall within Trask's well sorted category (sorting coefficient less than 2.5). The high degree of sorting

TABLE IV
FORAMINIFERA FROM SEDIMENTS OF RANGER BANK

	Sample Number		
	2	5	18
<i>Angulogerina carinata</i> Cushman	P ¹	P	
<i>A. semitrigona</i> (Galloway and Wissler)	P	P	P
<i>Astrononion viragoense</i> Cushman and Edwards	P		
<i>Bolivina accuminata</i> Natland	P		
<i>B. longi</i> Cushman	P		
<i>B. vaughani</i> Natland	P		
<i>Cancris auricula</i> (Fichtel and Moll)			P
<i>Cassidulina californica</i> Cushman and Hughes		P	3
<i>C. limbata</i> Cushman and Hughes	P	2	P
<i>C. quadrata</i> Cushman and Hughes	4	5	P
<i>C. tortuosa</i> Cushman and Hughes	3	1	1
<i>Cibicides</i> cf. <i>basiloba</i> Cushman	P	P	P
<i>C. gallowayi</i> Cushman and Valentine		P	
<i>C. ungeriana</i> (d'Orbigny)	P	P	P
<i>Elphidium articulatum</i> d'Orbigny			P
<i>E. cf. crispum</i> (Linné)	P	P	4
<i>Epistomina</i> sp.		P	P
<i>Eponides repandus</i> (Fichtel and Moll)		P	P
<i>Gaudryina</i> sp.	P		P
<i>Gigas quinqueloculina</i> Natland			P
<i>Globigerina bulloides</i> d'Orbigny	1	3	P
<i>G. conglomerata</i> Schwager	2	4	2
<i>Globigerinoides cyclostoma</i> (Galloway and Wissler)		P	P
<i>Globorotalia canariensis</i> (d'Orbigny)	P		
<i>G. truncatulinoidea</i> (d'Orbigny)		P	
<i>Guttulina quinquecosta</i> Cushman and Ozawa	P		
<i>Lagena orbignyana</i> (Sequenza) var. <i>elliptica</i> Cushman	P	P	
<i>Orbulina universa</i> d'Orbigny	P	P	P
<i>Planulina ariminensis</i> d'Orbigny	P	P	P
<i>Pullinia salisburyi</i> Stewart and Stewart		P	
<i>Pseudopolymorphina atlantica</i> Cushman and Ozawa			P
<i>P. doanei</i> (Galloway and Wissler)			P
<i>Quinqueloculina elongata</i> Natland	P	P	P
<i>Reophax depressa</i> Natland			P
<i>Robulus cushmani</i> Galloway and Wissler	P		P
<i>Sigmomorphina frondiculariformis</i> (Galloway and Wissler)	P	P	
<i>Sigmoilina tenuis</i> (Czjzek)	P		
<i>Triloculina trigonula</i> (Lamarck)		P	P

¹ P: present; 1 to 5: order of decreasing abundance for commonest species.

is also borne out by the fact that the cumulative curve of grain-size frequency is a steep nearly straight line when plotted on probability paper. Silt and clay (less than $\frac{1}{16}$ mm. diameter) is less than 2 per cent in all excepting sample 21, the least well sorted sample, which contains nearly 8 per cent of silt and clay. No relationship of median diameter with depth is present, but there is a very general increase of silt and clay percentage with depth. All samples containing more than

1 per cent of silt and clay are deeper than 80 fathoms, and the deepest sample, No. 21, has the highest percentage. If samples from greater depth on the bank were available they would probably be found to contain much more of the fine components. Samples from about 120 fathoms on the broad flat floor of Vizcaino Bay east of the area covered by Figure 1 show it to be floored by mud.

After the whole samples were digested in 1 normal HCl, the insoluble residue was screened and compared with the size distribution of the whole sample. Figure 4 shows that for all samples the insoluble material is concentrated in the finer components of the whole sample and that for most samples it comprises all of the material finer than $\frac{1}{8}$ mm. Thus, the coarser part of the whole samples is organic calcium carbonate, and the finer part is insoluble residue, mostly detrital mineral grains. This relationship suggests that once the large grains of organic shells and tests are reduced by comminution or solution to about $\frac{1}{8}$ mm. diameter, the grains have enough area exposed so that solution is accelerated and the rest of the grain dissolves quickly. As shown by Table III, the insoluble residue has a median diameter averaging 0.188 mm., only about $\frac{1}{2}$ that of the whole sample. Comparison of the median diameter of the insoluble residue with depth shows a close relationship, with coarser material on the bank top and finer down on its sides. In about half of the insoluble residues the sorting is better, and in half it is worse, than for the original whole sample. Neither the sorting coefficient nor the percentage of insoluble residue appears to be closely related to depth.

Composition.—Nearly the whole soluble part of the sediment samples consists of calcium carbonate. For the eleven samples of Table III, the soluble part averages 87 per cent. A more thorough study was made of three of these samples, one from each end and one from the middle of the bank (samples 1, 12, and 21). For these, the soluble part averages 69.6 per cent. Collophane, the chief mineral of phosphorite, constitutes only 0.4 per cent of this quantity. Collophane was also identified in every other sediment sample. The bulk of the soluble fraction, calcium carbonate, is the remains of shells and other organic debris. This material is highly variable in origin. A large percentage of the organic debris, 25 to 75, is composed of broken and corroded shells of pelecypods and gastropods. A few echinoid spines and plates and pieces of Bryozoa and *Lithothamnion* are also present. Some siliceous sponge spicules and diatoms are in the insoluble residue. Foraminifera constitute 10–70 per cent of the organic debris, with pelagic genera ranging between 5 and 70 per cent of the total number of tests. The appearance of typical untreated samples is shown by Figures 8 and 9. A list of Foraminifera identified by M. L. Natland in samples 2, 5, and 18 is given in Table IV. Altogether 38 species were identified, and in each of the three samples 23 to 25 of these were found. Twelve species occurred in all three samples, and ten species in two out of the three samples. Those species present only in one sample usually were based on only a single test; a more thorough search probably would have revealed their presence in the other samples. Each sample, thus, contains the same general fauna, which is marked particularly by abundance of *Cassidulina*.

This fauna is characteristic of Natland's Zone 3, comprising the depth range between 125 and 900 feet (12); this corresponds well with the actual depth from which the samples were collected, 486-612 feet (Table I). Most of the tests are worn and few were occupied by living Foraminifera at the time of sampling. Apparently no Foraminifera reworked from Pliocene or Miocene rocks were present.

The insoluble residue was placed in bromoform and separated into fractions of greater and lesser density than the 2.8 specific gravity of the liquid. As shown by Table III, the heavy fraction of most samples constitutes about 0.6 per cent of the entire sample, or 5 per cent of the total insoluble mineral grains. More complete mineralogical analyses were made of the sand-size fraction of samples 1, 12, and 21. The percentages of plagioclase, quartz, and orthoclase in the light fraction were determined by a combination of optical and staining methods (15). A part of the heavy fraction of each of the three samples was mounted in a 1.65 index of refraction oil and the mineral species were determined by ordinary optical methods. Percentages were based on counts of about 200 grains in each sample.

The results of the analyses are presented in Table V with the minerals grouped under headings of organic, authigenic, detrital light, and detrital heavy minerals. Glauconite constitutes most of the authigenic mineral grains, and if coprolites (faecal pellets) were excluded from the table as not being a mineral species, glauconite would be 98 per cent of the authigenics, leaving the remaining 2 per cent for collophane. Most of the glauconite is in the form of internal casts of Foraminifera (Fig. 10) and is not apparent until the enclosing tests are dissolved in acid. The detrital minerals found in the sediments are those which might be expected in accordance with the range from rhyolite to basalt of the rock specimens. Quartz and orthoclase are at the acidic end and olivine and magnetite are at the basic end of the scale. Hornblende constitutes nearly half of the heavy fraction, and may be partly metamorphic in origin. Glaucofane was found, but only in sample 21, which happens to be farthest from the area of the metamorphic rock samples. It is noteworthy that sample 12 contains no glauconite, or coprolites, only a few grains of collophane, and was coarse-grained with the lowest percentage of calcite of all samples from the bank; therefore, it may be of different origin from the other samples. Possibly it is a former beach sand. Most of the coarse detrital grains of each sample are angular, suggesting that they were not transported far or long enough to be worn very much.

A similar analysis was made of the mineral content of about 12 pieces of phosphorite from samples 7 and 11. The results, given in Table V, are somewhat different from those of the sediments. Orthoclase is much more abundant and plagioclase and quartz much less abundant in the phosphorite. For ease in comparison, the heavy minerals of Table V are in two groups: those which are more abundant in the sediments, and those more abundant in phosphorite. Those more abundant in the phosphorite include the more basic minerals and those minerals like titanite, zircon, epidote, and ilmenite which are highly resistant to weathering

and abrasion. The phosphorite also contains an interesting authigenic mineral, barite. The barite occurs as a replacement of the opal of the disk-like diatom, *Coscinodiscus*. Its identification is based on optical measurements, chemical tests,

TABLE V
MINERALS IN SEDIMENTS AND PHOSPHORITE

	<i>Sediments</i> <i>Average of Samples</i> <i>1, 12, 21</i>	<i>Phosphorite</i> <i>Average of Samples</i> <i>7, 11</i>
ORGANIC—calcite.....	69.2%	0.0%
AUTHIGENIC		
Glauconite	75.5%	0.2%
Coprolites	22.3	0.0
Collophane	2.2	99.3
Barite	0.0	0.5
	100.0%.....17.9	100.0%.....93.0
DETRITAL LIGHT		
Plagioclase	47.0%	28.0%
Quartz	43.0	18.0
Orthoclase	10.0	54.0
	100.0%.....11.5	100.0%.....6.5
DETRITAL HEAVY		
Hornblende	47.2%	23.2%
Hypersthene	7.0	2.6
Apatite	3.7	0.5
Actinolite	2.3	1.6
Augite	2.1	1.5
Chlorite	0.7	0.0
Glaucophane	0.5	0.0
Olivine	8.6	9.3
Magnetite	7.9	15.6
Titanite	4.4	5.7
Clinozoisite	3.0	8.3
Garnet	3.0	3.6
Zircon	2.6	4.7
Epidote	1.9	5.7
Biotite	1.6	3.6
Zoisite	1.4	2.6
Ilmenite	0.9	3.1
Leucoxene	0.5	5.2
Diopside	0.5	1.0
Spinel	0.2	0.5
Rutile	0.0	1.6
	100.0%.....1.4	100.0%.....0.5
	100.0%	100.0%

and its high specific gravity. The causes and nature of such replacement by barite constitutes an interesting side problem.

CONCLUSIONS

The collections and other data available for Ranger Bank are sufficiently detailed to warrant the making of some suggestions regarding its geological history.

The distribution of rocks suggests that the bank is mainly composed of metamorphic rocks, probably Jurassic in age, and of volcanic rocks, probably Miocene in age. Some of these rocks were altered by hydrothermal action followed by burial beneath Miocene and possibly other sediments. After consolidation of the sediments the bank was formed by faulting and was bevelled by wave erosion which cut across sedimentary, igneous, and metamorphic rocks alike. The erosion produced the rounded cobbles and pebbles and the thin layer of well sorted and evidently transported sand which remains on the bank surface. After it was bevelled the bank became more deeply submerged, or the sea level rose, so that its top is now 67 fathoms deep. The bank now serves as a site for the very slow formation and accumulation of calcareous organic debris, glauconite, and perhaps phosphorite. During times of large waves the wave motion extends to the bottom where it is strong enough to produce faint oscillation ripple-marks on the thin sandy surface and also to winnow out any fine clays that might have been deposited from suspension or have been weathered from the bottom materials. The bottom currents appear to be so weak, however, that they are unable to move pebbles and rocks which, in consequence, have become covered by encrusting organisms.

Two of the rock types deserve special mention. The glaucophane schist is similar to the Franciscan (Jurassic ?) schist of California and if it really is the same rock, the outcrops on Ranger Bank are the southernmost known to the writer. The phosphorite found in abundance on the bank is the other kind of rock of greatest interest. It contains Miocene Foraminifera, an assemblage of heavy minerals slightly different from that of the enclosing sediment, and has a pebble-size distribution somewhat like that of other kinds of rock fragments collected in the same dredgings. These facts suggest that it was eroded from Miocene rocks and concentrated on the unconformity. The very great abundance of phosphorite in similar samples from off southern California has led to an alternate suggestion that some of the phosphorite of that area may be a contemporary blanketing deposit. If the phosphorite is of Miocene age, the Miocene rocks must have contained much more phosphorite than is common at land outcrops and the phosphorite must have been much more resistant to weathering than the enclosing sediments so that it remains as a residual concentrate.

Petroleum geologists, after presenting the pertinent descriptive data of an oil structure, usually try to estimate the environment in which the sediments were originally deposited. It may be appropriate in the case of Ranger Bank, where the environment of deposition is known, to speculate in a reverse direction about the final structure that is likely to be found by an imaginary future well driller. No very appreciable quantity of fine-grained sediments should accumulate on the top of the bank until muds deposited in surrounding areas have become flush with the bank top. Fine sediments can not stay on the bank top because any lateral shifting of the grains by waves and currents must necessarily result in a slow net transport down the slope and away from the top (14). Consequently, only the coarse-

grained glauconite and organic débris will mantle the bank, and these form extremely slowly. After the bank is completely buried by muds, it is possible that a slow prograding of the sandy beach may result in the deposition of a sand layer of regional dimensions. By continued compaction of the thick muds around the bank the sandstone would form an anticlinal structure with the crest above the bank top and the flanks above the bank's side slopes in the manner suggested by Athy (1) and others to explain "buried hill" structures. If a suitable impervious cap and an oil source shale were present, oil could accumulate in the sandstone. By drilling deeper, an imaginary future driller would find a thin deposit of glauconite, shells, phosphorite, and rounded pebbles overlying an unconformity, a common association in ancient sediments. Ripple marks should show up in some cores. This horizon would extend laterally for only a few miles. Below the unconformity, the drill would strike metamorphic, igneous, and sedimentary rocks different from those above. Some oil accumulation might be present in the weathered rock surface and in the thin overlying sands, the oil having come either from overlying source beds or from the truncated Miocene mudstones. There might also be accumulation in the bevelled edges of the Miocene sandstones. Whether or not this interpretation is correct in detail, such estimates may be of assistance in understanding the origin and character of some similar oil structures already discovered and now being explored. Some of the processes now operative on Ranger Bank must have been active also on the buried flat-topped pre-Cambrian hills in Kansas (19) as well as on others known in Missouri (3), in Oklahoma (9), and elsewhere (13).

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SILETZ RIVER VOLCANIC SERIES, NORTHWESTERN OREGON¹

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ABSTRACT

The name Siletz River volcanic series is proposed for more than 3,000-5,000 feet of basaltic flows, flow breccia and tuff, in which are included a few beds of clastic sedimentary rocks that contain a fauna correlative with the Capay shale of California. The volcanic series is correlated with the Umpqua formation of southwestern Oregon and with the lower part of the Tillamook volcanic series of northwestern Oregon.

INTRODUCTION

A thick series of basaltic flows, pillow lavas, flow breccias, and pyroclastic rocks that includes small amounts of water-laid tuffaceous sedimentary rocks is exposed along the Siletz River and its tributaries in the Coast Range of Oregon. Field investigations by the United States Geological Survey in the Euchre Mountain and Nestucca Bay quadrangles and by the Oregon Department of Geology and Mineral Industries in the adjoining Dallas and Valsetz quadrangles have shown that this series is a mappable unit which can not be directly correlated with other Eocene volcanic rocks in Oregon. The series is equivalent to the lower part of the Tillamook volcanic series described by Warren, Norbistrath, and Grivetti (1945). Recent field studies by Snavely have shown that upper and middle (?) Eocene sedimentary rocks overlying the volcanic rocks along the Siletz River interfinger with the Tillamook volcanic series in the Nestucca Bay Quadrangle. This makes it desirable to describe as a separate unit the older volcanic rocks along the Siletz River. The name Siletz River volcanic series is proposed for these volcanics.

TYPE LOCALITY

The Siletz River volcanic series is best exposed along the Siletz River and its tributaries in the Euchre Mountain and Valsetz quadrangles. The exposure along the Siletz River from the Valsetz milldam (Sec. 28, T. 8 S., R. 8 W.) to the Lower Gorge (Sec. 16, T. 9 S., R. 9 W.) is designated as the type section. The Werner Lumber Company logging road, and its continuation in the Western Logging Company road, also furnishes an excellent section across the volcanic mass in the east-central part of the Euchre Mountain Quadrangle.

¹ Published by permission of the director of the United States Geological Survey and Oregon Department of Geology and Mineral Industries. Manuscript received, March 25, 1948. The writers wish to acknowledge the faunal data contributed by H. E. Vokes of The Johns Hopkins University and J. Wyatt Durham of the University of California, and the petrographic descriptions of this volcanic series in the Valsetz and Dallas quadrangles contributed by W. D. Lowry, then of the Oregon Department of Geology. Vokes has also assisted the writers during the preparation of this report.

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GEOLOGY OF VOLCANIC ROCKS

General field relations.—The Siletz River volcanic series includes the oldest rocks in the central part of the Coast Range, constituting the rugged, highland areas in the east-central part of the Euchre Mountain Quadrangle, the northern half of the Valsetz Quadrangle, and northwestern corner of the Dallas Quadrangle. The volcanic rocks are overlain with apparent conformity, except where faulting has produced local angular relationships, by rhythmically bedded micaceous, arkosic sandstones of middle (?) Eocene age. Small erosional outliers of these sandstones protected by remnants of sills and by faulting occur within the volcanic mass. In the northwestern part of the area underlain by the Siletz River volcanic series, upper Eocene tuffaceous siltstones unconformably overlap the middle (?) Eocene sandstones to rest directly on the volcanics. Along a part of the east west boundaries of the area of volcanic rocks, these rocks are in fault contact with the younger sedimentary rocks (Fig. 1). This relationship is evident on the Werner Lumber Company road in Sec. 21, T. 8 S., R. 10 W., and in the vicinity of the Valsetz milldam. The volcanic rocks are on the upthrown side of both faults.

The base of the Siletz River volcanic series is not exposed in the area, but a minimum thickness of 3,000–5,000 feet has been computed for the section between Valsetz and the forks of the Siletz River. This computed thickness is conservative, allowing for some initial dip and for some duplication by faulting.

Structurally the volcanics are folded into broad anticlinal arches with minor flexures. One arch trends northward along the western half of the mass, plunging northeast; the other trends a little north of east and plunges beneath the Willamette Valley near Dallas. The volcanic series appears to steepen west of Valsetz along the south fork of the Siletz River. This steepening is probably caused by rotation of blocks along parallel faults. Dips as steep as 45° were observed. Small faults and irregular shear zones occur throughout the series.

Petrographic description.—The Siletz River volcanic series consists chiefly of ferromagnesian lava flows but includes flow breccias, pyroclastic rocks, and small amounts of sedimentary beds. The predominant rock in the flows is a dark greenish gray aphanitic to porphyritic basalt. Rectangular phenocrysts of plagioclase and equant-to-rounded phenocrysts of augite are visible in hand samples. Vesicular and amygdaloidal basalts are common, with the amygdules composed of radiating zeolites and calcite. Unaltered basalt is rare, and locally chloritization is so advanced that a greenstone has resulted. Typical pillow structure is common through the series (Fig. 2–3), individual pillows averaging 3 feet in diameter. Columnar joints which radiate from the center of the essentially ellipsoidal pillows can be seen in most exposures. Flow breccia is not rare (Fig. 4), and is probably the result of autobrecciation by steam explosion which accompanies submarine extrusion. Sporadic pillows are found in many of the flow breccias, testifying to their subaqueous origin.

Microscopic study shows that the basalt is holocrystalline to hemicrystalline

with porphyritic to glomeroporphyritic and vesicular textures. The groundmass varies from trachytic to intersertal. Phenocrysts of plagioclase (Ab_4 An_6 to Ab_3 An_7 labradorite) and augite are set in a groundmass of plagioclase laths (Ab_5 An_6 to Ab_4 An_6 labradorite), granules of augite and magnetite, and volcanic glass. The phenocrysts and laths of plagioclase constitute about 50 per cent of the total rock. Some of the phenocrysts contain fractures which do not extend into the groundmass. Augite phenocrysts and granules constitute 2-25 per cent of the basalt with only 1-5 per cent occurring as phenocrysts. Magnetite is an important constituent of the groundmass, forming 5-15 per cent of the sections. Glass in the groundmass of the basalt forms 15-65 per cent of the sections, averaging 30 per cent. In several of the basalts the glass was partly devitrified and altered to palagonite.

A hydrothermal type of alteration of the Siletz River volcanics has developed abundant secondary minerals. Zeolitic minerals (stilbite, mordenite, and natrolite) are common in most of the basalt and breccia, making up as much as 30 per cent of some sections. Calcite is abundant, filling vesicles and irregular fractures, and chloritic minerals are present in most of the sections studied. Other secondary products identified are: palagonite, epidote, opal, analcite, limonite, and serpentine.

The pyroclastic rocks range from fine tuff to agglomerate. Lapilli tuff composed of a heterogeneous mixture of varicolored basaltic fragments is the most abundant type. In some exposures the fine tuff contains sporadic blocks of dense basalt. Microscopically the tuff contains altered basaltic fragments, calcic feldspar, and augite crystals set in a groundmass of opal, palagonite, calcite, and chloritic minerals. The interbedded sedimentary rocks are predominant water-laid tuff and tuffaceous siltstone and sandstone, with subordinate amounts of basaltic grits, sandstone, and conglomerate. Some of the finer tuff closely resembles a well indurated carbonaceous siltstone. These tuffaceous sediments weather to spheroidal masses, each concentric shell being coated with a film of manganese dioxide. Dikes, sills, and stock-like intrusives of a younger generation of igneous activity cut the Siletz River volcanic series in many places. These will be described elsewhere.⁴

Age and correlation.—Collections of fossils were made from beds of tuffaceous material in the upper part of the Siletz River volcanic series at one locality in the southwestern part of the Nestucca Bay Quadrangle and at two localities in the northern half of the Euchre Mountain Quadrangle. These fossils were identified by H. E. Vokes of The Johns Hopkins University and are here listed.

It is to be noted that all of the previously described species found at these three localities also occur in the fauna of the Umpqua formation which is correlated with the Capay in the Eocene sequence of the California. There can, there-

⁴ E. M. Baldwin, W. D. Lowry, and P. D. Snavely, Jr., "Sill-Like Intrusives in the Central Coast Range of Oregon." In preparation.

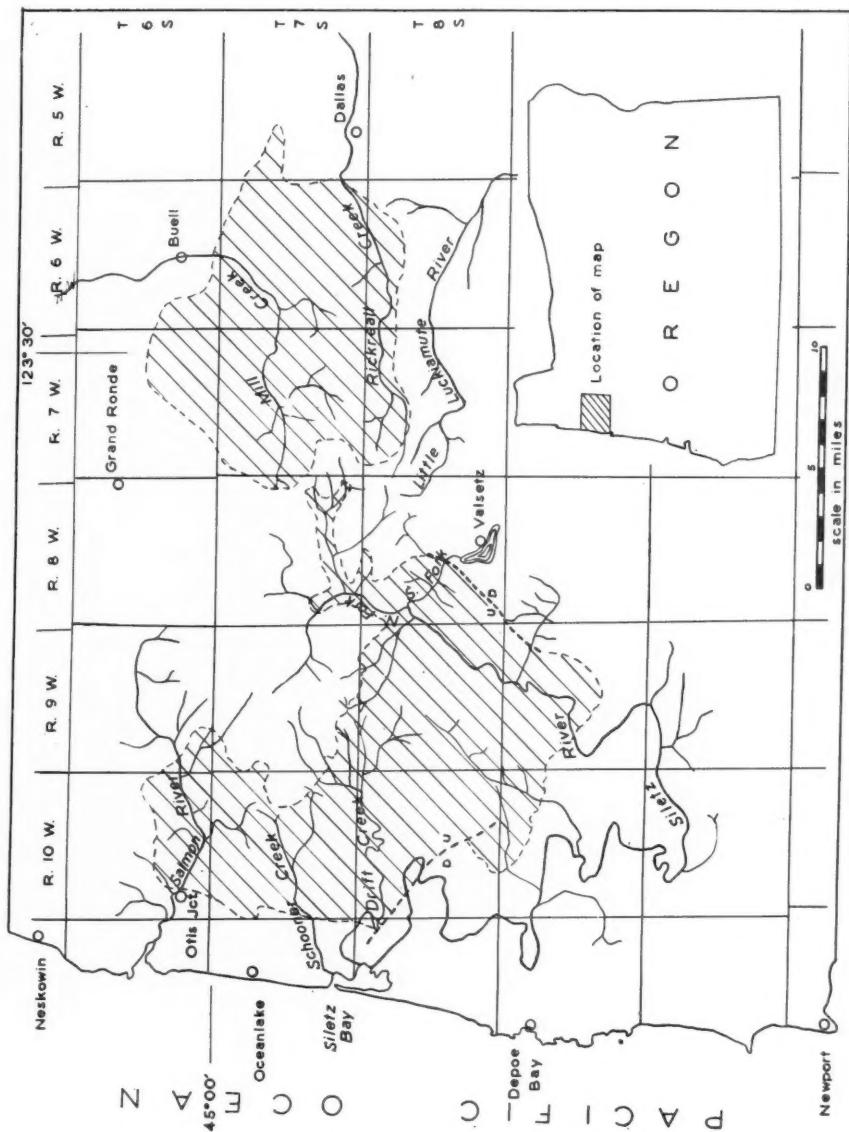


FIG. 1.—Geologic sketch map showing areal distribution of Siletz River volcanic series.

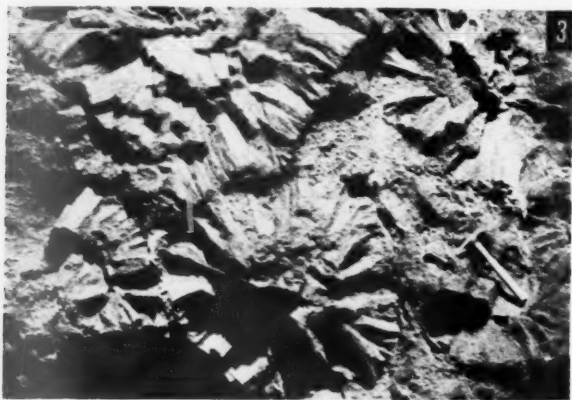
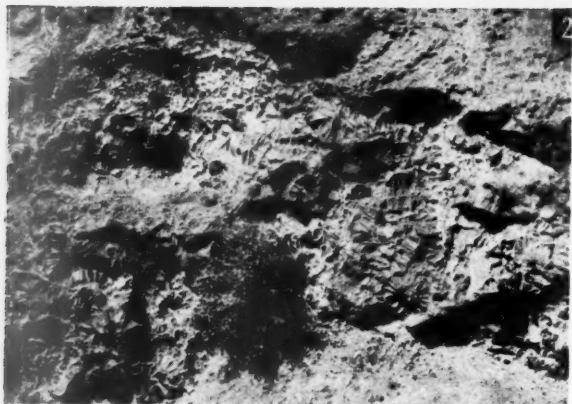


FIG. 2.—Pillow structures in Siletz River volcanic series in quarry 5 miles east of Otis Junction, Oregon. Width of area in picture, 45 feet.

FIG. 3.—Close-up of Figure 2 showing radiating columnar joints in individual pillows.

FIG. 4.—Flow breccia at Falls of Siletz River, Valsetz Quadrangle, Oregon. Standard field notebook indicates scale.

fore, be little doubt as to the Capay age of the fauna that occurs within the upper part of the volcanic series.

A collection made from a tuffaceous lens in a quarry about $2\frac{1}{2}$ miles west of Dallas in Sec. 25, T. 7 S., R. 6 W., contained nearly 30 species of fossils which were identified by J. Wyatt Durham of the University of California. He stated:

On the basis of the brachiopoda, and particularly *Turritella andersoni* cf. *subsp.*

	Otis Jct. ⁶	Bear Creek ⁶	Werner Road ⁷	Umpqua- Capay	Tyee- Dom- engine	Coaledo- Spencer- Tejon
<i>Barbatia</i> (<i>Barbatia</i>) n. sp.	x	—	—	—	—	—
<i>Glycymeris</i> cf. <i>perrini</i> Dickerson	x	—	—	x	—	—
<i>Ostrea</i> sp.	x	x	—	—	—	—
<i>Lima</i> n. sp.	x	—	?	—	—	—
<i>Venericardia</i> sp. indet.	x	—	x	—	—	—
<i>Lucina roseburgensis</i> Turner	cf.	x	—	x	—	—
<i>Nemocardium linteum</i> (Conrad)	x	x	x	x	x	—
<i>Plagiocardium breweri</i> (Gabb)	x	—	x	x	x	x
<i>Pitar wasanus duprei</i> Turner	—	—	x	x	x	—
<i>Spisula merriami longifrons</i> Turner	—	—	x	x	—	—
<i>Ampullina andersoni</i> (Dickerson)	—	—	cf.	x	—	—
<i>Amaurellina hendoni</i> Turner	—	x	—	x	x	—
<i>Neverita globosa</i> (Gabb)	—	x	—	x	x	x
<i>Turritella andersoni glidensis</i> Merriam	cf.	—	—	x	—	—
<i>Turritella buwaldana coosensis</i> Merriam	—	—	x	x	x	—
<i>Cerithiopsis excelsa</i> (Dall)	—	x	x	x	x	—
<i>Rimella macilenta oregonensis</i> Turner	—	x	—	x	—	—
<i>Mitra cretacea</i> Gabb, var.	—	x	—	—	—	—
<i>Exilia</i> sp.	—	x	—	x	x	x
<i>Scaphander costatus</i> (Gabb)	—	x	x	x	x	x
<i>Cylichmina tantilla</i> (Anderson & Hanna)	x	x	—	x	x	—
<i>Discocyclina</i> (<i>Proporocyclina</i>) <i>psila</i> Woodr.	x	—	x	x	—	—

⁶ Locality on south side of Salmon highway 0.4 mile east of Otis Junction, Oregon.

⁶ Locality in NW $\frac{1}{4}$, Sec. 10, T. 7 S., R. 10 W., Euchre Mountain Quadrangle, Oregon.

⁷ Locality along Werner Logging Company road in SW $\frac{1}{4}$, Sec. 16, T. 8 S., R. 9 W., Euchre Mountain Quadrangle, Oregon.

susanae Merriam, this fauna appears to be about equivalent in age to the Capay stage of the Eocene of California.

The bryozoa, calcareous algae, *Spondylus*, *Acmaea*, *Nerita*, etc., indicate that the containing sediments were probably deposited in water less than 20 meters deep, and of a tropical temperature.

Another collection from a north fork of Sunshine Creek, Valsetz Quadrangle, and likewise near the top of the volcanics was also studied by Durham who gave it the following age assignment.

Age Eocene, probably equivalent in age to Capay or Domengine stages of California; most likely Capay. Equivalent to part of Crescent formation (S.L.) of Washington. Determination based on the corals plus general appearance of the fauna. Deposited in water less than 37 meters in depth on basis of reef dwelling type of corals and *Spondylus*. The corals also indicate an average yearly minimum marine temperature of not less than 20°C.

Volcanics of similar composition and apparently of similar age are interbedded with the Umpqua formation in southwestern Oregon, which has been correlated by Turner (1938, p. 7) with the Capay of California. Sediments of the Crescent formation of northwestern Washington are interfingering with similar volcanics which have likewise been correlated by Berthiaume (1938, p. 495) with the Capay as well as with the Umpqua formation on the basis of microfauna. In western Oregon and Washington this part of the Tertiary was evidently the scene of widespread volcanism accompanied by deposition of varying thicknesses of tuffaceous sediment. Near the centers of volcanism the series are very thick.

A series of later Eocene volcanic rocks which interfinger with sediments that contain fauna of the Cowlitz formation has been recognized in western Washington and Oregon by Berthiaume (1938, p. 495) and Durham (1944, p. 105), and a thick series of this age along the lower course of the Columbia River has been named the Goble volcanic series and is described by Lowry and Baldwin (Wilkinson, Lowry, and Baldwin, 1946). Volcanics of upper Eocene age have also been recognized by Snavely along the coastal area of northwest Oregon in the Nestucca Bay Quadrangle.⁸ Throughout most of western Oregon the volcanics and associated sedimentary rocks of upper Eocene age are separated from those of upper Eocene age by a major unconformity.

The rocks in a large area in northwestern Oregon, consisting of basaltic flows, breccia, tuff, and some beds of sedimentary rocks, have been named and described as the Tillamook volcanic series by Warren, Norbistrath, and Grivetti (1945). Lack of paleontological data made it difficult for them to determine the exact stratigraphic range of these volcanics. Mapping in the Nestucca Bay Quadrangle outside of the area studied by these authors indicates that both the middle (?) Eocene sandstones which overlies the Siletz River volcanic series and shales and sandstones containing a Cowlitz fauna interfinger with the upper part of the Tillamook volcanic series.

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⁸ P. D. Snavely, Jr., and H. E. Vokes, "Geology of the Oregon Coast between Cape Kiwanda and Cape Foulweather." In preparation.

GEOLOGICAL NOTES

HUGOTON EMBAYMENT OF ANADARKO BASIN IN SOUTHWESTERN KANSAS, SOUTHEASTERN COLORADO, AND OKLAHOMA PANHANDLE¹

JOHN C. MAHER² AND JACK B. COLLINS²
Tulsa, Oklahoma

The term "Dodge City basin" was applied by McClellan³ in 1930 to the relatively unexplored synclinal area of southwestern Kansas into which the Paleozoic

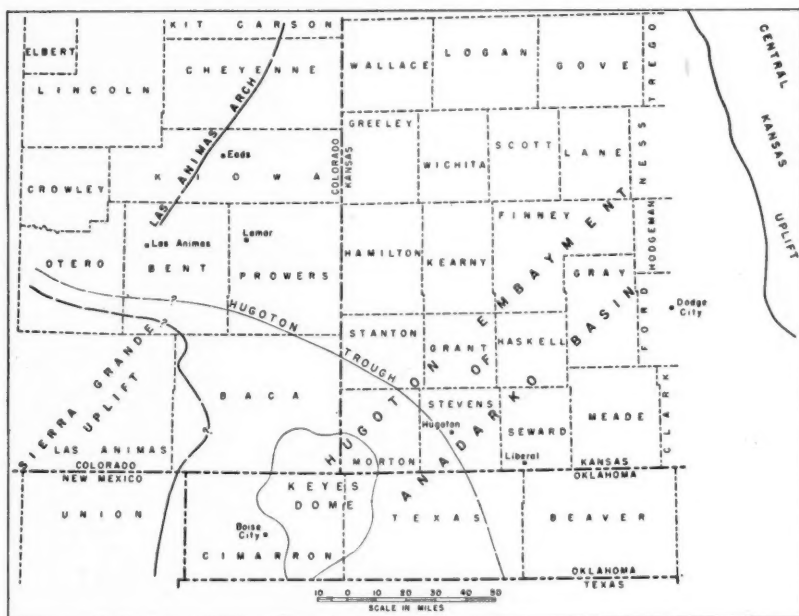


FIG. 1.—General structural features of Mississippian rocks in southwestern Kansas, southeastern Colorado, and Oklahoma Panhandle.

¹ Manuscript received, March 30, 1948. Published by permission of the director of the United States Geological Survey.

² United States Geological Survey.

³ Hugh W. McClellan, "Subsurface Distribution of Pre-Mississippian Rocks of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 12 (December, 1930), p. 1550.

rocks dip off the west flank of the Central Kansas uplift. The northern, western, and southern boundaries of this basin were not described or shown by diagram for the very good reason that few deep wells had been drilled in western Kansas, eastern Colorado, and the Oklahoma Panhandle at that time. Recently Wheeler⁴ in his paper on the geology and oil possibilities of the Anadarko basin of Oklahoma included in the Anadarko basin parts of Stevens, Seward, Meade, and

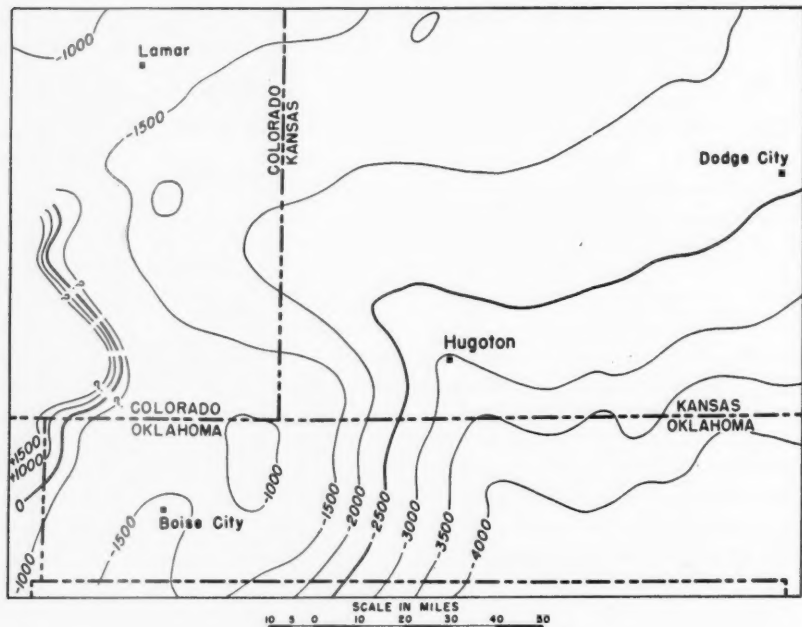


FIG. 2.—Structure of Mississippian rocks in southwestern Kansas, southeastern Colorado, and Oklahoma Panhandle. Contours on top of Mississippian.

Clark counties in southwestern Kansas, and Beaver County and parts of Texas and Ellis counties in the Oklahoma Panhandle, and applied the name "Dodge City embayment" to this area. The writers believe that this embayment extends northward and westward to include the area between the Sierra Grande uplift, the Las Animas arch, and the Central Kansas uplift, as shown in Figure 1, and that the Keyes dome and the undefined anticlinal features east of Liberal, Kansas, may be considered within the embayment. This embayment has an asymmetric shape, with the deeper part or trough at the southwest. The geographic name

⁴ Robert R. Wheeler, "Anadarko Basin—Geology and Oil Possibilities," *World Oil*, Vol. 127, No. 4 (September 22, 1947), p. 37.

"Hugoton" appears to be more appropriate for this embayment and trough than "Dodge City" for the following reasons.

1. The axis of the trough extends northwestward across the southwestern

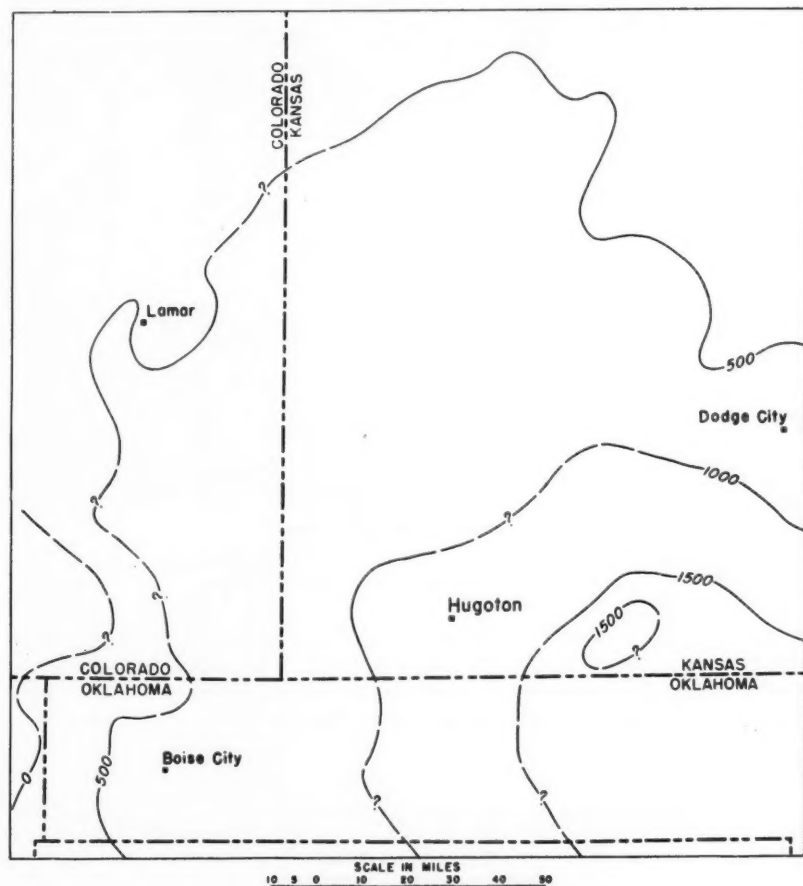


FIG. 3.—Thickness of Mississippian rocks in southwestern Kansas, southeastern Colorado, and Oklahoma Panhandle.

corner of Kansas near the town of Hugoton, which is about 85 miles southwest of Dodge City (Figs. 1 and 2).

2. The thickest deposits of Pennsylvanian and Mississippian rocks are known to lie considerably southwest of Dodge City (Fig. 3 for thickness of Mississippian rocks).

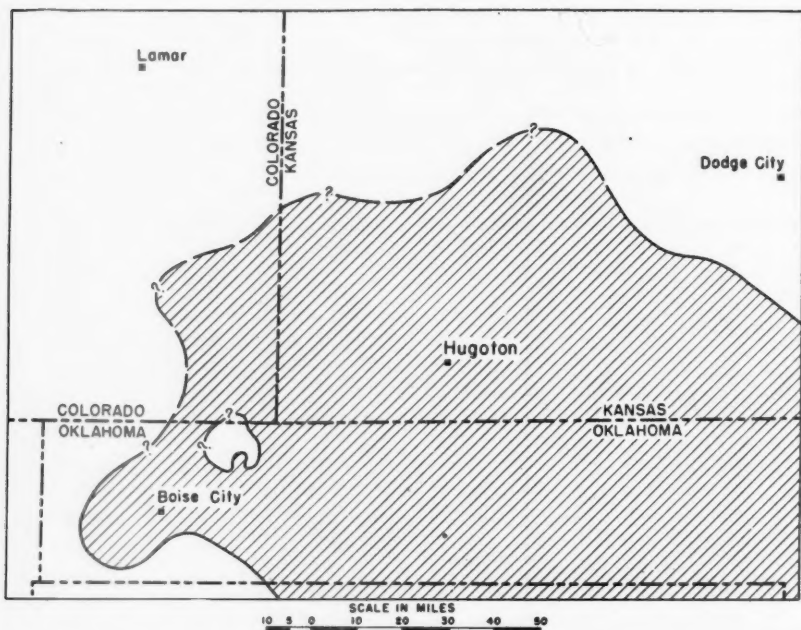


FIG. 4.—Distribution of Upper Mississippian (Chester) rocks in southwestern Kansas, southeastern Colorado, and Oklahoma Panhandle.

3. Lower Pennsylvanian (Atoka and Morrow) rocks and Upper Mississippian (Chester) rocks are present only in the deeper part of the embayment south and west of Dodge City. The town of Hugoton lies near the center of the area underlain by Upper Mississippian (Chester) rocks (Fig. 4).

UPPER DEVONIAN BENTONITE IN TENNESSEE¹

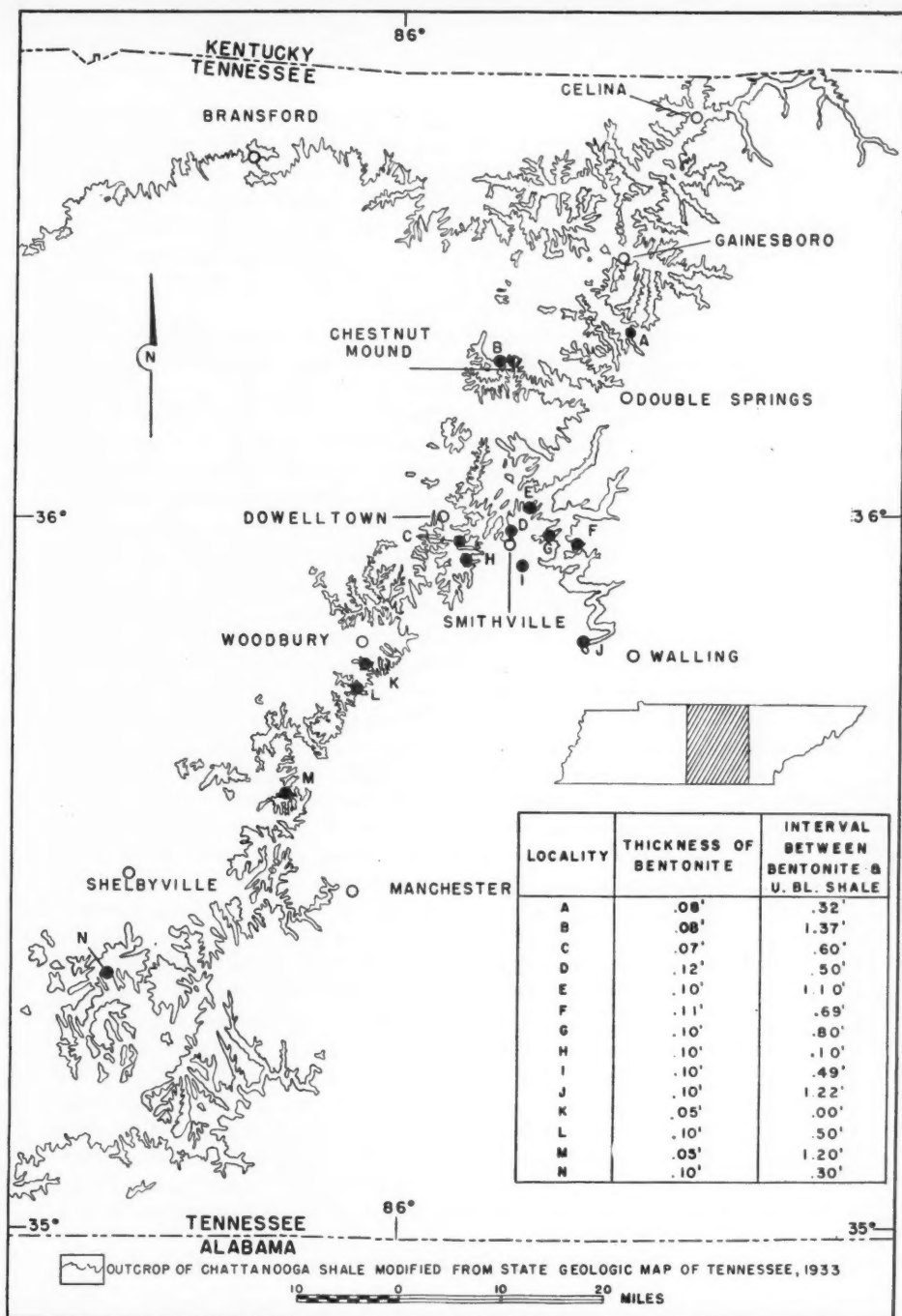
WILBERT H. HASS²

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During recent stratigraphic work on the Chattanooga shale of the eastern Highland Rim of Tennessee a thin bed of bentonite was recognized in the Upper Devonian part of that formation. This bentonite, which averages one-tenth of a foot in thickness and resembles the Ordovician bentonites, is a singular bed and, as such, is an excellent stratigraphic datum. Its present extent is not known;

¹ Published by permission of the director of the United States Geological Survey. Manuscript received, April 29, 1948.

² Geologist, United States Geological Survey.



BENTONITE LOCALITIES, EASTERN HIGHLAND RIM, TENNESSEE

presumably it is present over more than 3,000 square miles of east-central Tennessee for it has been seen from the Flynns Lick area north of Double Springs to the vicinity of Shelbyville—a distance of over 80 miles along the strike (see map). In this area, the Chattanooga shale, except in the southernmost part where the lower portion is missing, consists of three lithologic units—an upper and a lower black shale and a middle gray siltstone. The bentonite is in the topmost portion of the middle gray siltstone, a unit that Campbell placed in the upper part of the lower member of his Dowelltown formation.³

Although the appearance of the bed varies as a result of the conditions under which it weathers, it is, nevertheless, easily recognized at the outcrop. The very abundant fresh biotite, or where weathered, the bleached biotite is easily seen with a hand lens. Fresh or slightly weathered material is dark gray and that color characterizes the bed where it has been recently exposed or is constantly wet. Being less resistant to weathering than the adjacent siltstones, the bed, in wet places, generally forms a slight recess along the face of the outcrop. A sample of the fresh material was examined by Clarence S. Ross who reports that all or nearly all of the material is of volcanic origin and that the groundmass consists of clay whose indices of refraction indicate that it is the potash type of bentonite. This is confirmed by chemical tests that indicate essential amounts of potash. A detailed study of material from Horseshoe Bend, on Caney Fork River, White County, indicates that fresh material contains about 30 per cent of biotite, some as euhedral grains. Other crystal grains form about 8 per cent of the whole. Of these about 49 per cent are orthoclase, about 43 per cent sodic plagioclase, and only about 8 per cent quartz. Thus the mineral composition is typically that of a volcanic rock. The clay groundmass was probably originally a glass. Ross also reports that the clay fraction resembles, and the biotite is similar to, that present in most Ordovician bentonites. At most exposures the bentonite finally weathers to a light gray, iron-oxide-stained band that is easily distinguished from the adjacent darker gray siltstones. The most weathered portion of the bed is nearly white and Ross finds that it consists of kaolinitic clay, quartz, and abundant bleached biotite. A few grains of marcasite are also present.

Nothing is known of the volcanic source and little of the conditions under which the bed was deposited. Presumably the source was not in the immediate vicinity of the eastern Highland Rim as otherwise the bentonite, somewhere along the outcrop, would be much thicker than it is. (See map for thickness of bed.) It also appears likely that the water into which the volcanic material fell was relatively quiet, inasmuch as agitation would certainly have resulted not only in a mixing of the volcanic ejecta with ordinary sediments but also in a removing of these ejecta from some areas through the action of currents. Investigations to date indicate that the bed is absent from only one area between Flynns Lick and the vicinity of Shelbyville. This area, an estimated 100 square miles, is

³ Guy Campbell, "New Albany Shale," *Bull. Geol. Soc. America*, Vol. 57 (1946), pp. 880-87.

located immediately on the north and east of Woodbury. There, owing to the absence of the bentonite, it is believed that there is an unconformity between the middle gray siltstone and the upper black shale. However, few beds are missing, because the stratigraphic sequence is similar to that of adjacent areas except for the absence of the bentonite. On the map, the thickness of that portion of the middle gray siltstone lying between the bentonite and the base of the upper black shale is given for each of the localities as an aid to locating the bentonite at the outcrop.

Acknowledgments are due Louis C. Conant who found the bentonite in the vicinity of Woodbury and Shelbyville and Clarence S. Ross whose laboratory report has been used in the preparation of this note.

LIST OF BENTONITE LOCALITIES

- A. Flynns Lick Creek, County road, 1.2 miles west of Tenn. Hy. 56, 7.3 miles north of Double Springs, Jackson Co.
- B. U. S. Hy. 70 N., .8 mile west of Chestnut Mound, Smith Co.
- C. Tenn. Hy. 26, 3.1 miles east of Dowelltown, Dekalb Co. The type locality of Campbell's Dowelltown formation.
- D. Holmes Creek road, 1.6 miles north of Smithville, Dekalb Co.
- E. Tenn. Hy. 56, 6 miles north of Smithville, Dekalb Co.
- F. Tenn. Hy. 26, about .5 mile east of Caney Fork River, Dekalb Co. The outcrop is a cut on a portion of the highway abandoned in 1948.
- G. Tenn. Hy. 26, about .5 mile west of Caney Fork River, Dekalb Co. The outcrop is a cut on a portion of the highway abandoned in 1948.
- H. County road, .5 mile east of Dry Fork school, Dekalb Co.
- I. Waterfall on Jake Poss' farm, 2.5 miles (airline) southeast of Smithville, Dekalb Co.
- J. Near camp site, south bank of Caney Fork River, near northernmost point of Horseshoe Bend, 4.75 miles (airline) west-northwest of Walling, White Co.
- K. Tenn. Hy. 53, 2.5 miles south of Junction with U. S. Hy. 70 S at Woodbury, Cannon Co.
- L. County road to Burt, 1.4 miles west of Tenn. Hy. 53, Cannon Co.
- M. U. S. Hy. 41, Noah road cut, 10 miles northwest of Manchester, Coffee Co.
- N. Tenn. Hy. 241, 14.8 miles south of Shelbyville, Bedford Co.

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

SECONDARY RECOVERY OF PETROLEUM IN ARKANSAS— A SURVEY, BY GEORGE H. FANCHER AND DONALD K. MACKAY

REVIEW BY PAUL D. TORREY¹
Houston, Texas

Secondary Recovery of Petroleum in Arkansas—A Survey, by George H. Fancher and Donald K. MacKay. Arkansas Oil and Gas Commission, El Dorado (1946). 250 pp. Clothbound. Price, \$15.00.

Secondary Recovery of Petroleum in Arkansas—A Survey is the result of the first detailed study by any State, of the recovery possibilities of its oil fields. The study on which this volume is based was authorized by the 54th General Assembly of Arkansas, and was commenced in the early part of 1943 under the direction of the Arkansas Oil and Gas Commission. The work was completed during the latter part of 1946.

In initiating this study and carrying it through to successful completion, Arkansas has continued to pioneer in conservation measures. The splendid conservation laws of Arkansas, regulating the production of oil and gas, are recognized generally as being among the best in the country. They have served as a model for many of the other oil-producing states.

In addition to its value from the standpoint of oil conservation, *Secondary Recovery of Petroleum in Arkansas—A Survey* contains a tremendous amount of geologic and engineering data on every notable oil field in Arkansas. It will, therefore, serve as an extremely valuable and convenient reference on almost every phase of oil production in the state. Considering the fact that many of the older fields were developed at a time when complete records were not considered essential, the amount of detailed data that the authors have assembled on every important field is truly amazing and reflects great credit on their diligence and perseverance.

Each important oil field in Arkansas is discussed in a separate chapter which includes: a historical account of discovery and development, a discussion of the stratigraphy and structure of the field, a description of the oil-bearing rocks, data on reservoir characteristics and performance, results of past and current secondary-recovery operations, and a consideration of future secondary-recovery possibilities. Thirty-seven oil fields are considered individually, and 14 relatively unimportant or new areas are considered in one chapter.

Production records are presented in graphic form, and are clear and easily read. The numerous geologic maps represent attention to scientific detail which has resulted in a superior illustration of structural conditions.

The authors conclude that from approximately 204 to 262 million barrels of oil may be recovered from Arkansas fields by the proper application of secondary methods. This secondary reserve is virtually equivalent to the recognized primary oil reserve of the state, and it is particularly significant because of the current low rate of discovery of new fields. It has been estimated that the secondary reserve is more than 40 times the new oil found in 1946.

¹ Petroleum engineer, 229 Shell Building. Review received, March, 1948.

The authors and the State of Arkansas are to be complimented for this outstanding contribution to the technology of oil recovery. In directing attention to methods by which substantial increases in oil recovery can be obtained from proved reserves, which do not require discovery, a distinct service has been performed to the Nation as well as to Arkansas. The very effective demonstration of the effectiveness of secondary methods for improving the efficiency of oil recovery is most impressive, and certainly should be considered by every State which may be concerned about the future of its petroleum industry.

RECENT PUBLICATIONS

AFRICA

*"The Rift Valleys of Africa," by G. F. S. Hills. *Amer. Jour. Sci.*, Vol. 246, No. 3 (New Haven, Connecticut, March, 1948), pp. 171-81.

COLORADO

"Geology of Southern Part of Archuleta County, Colorado," by G. H. Wood, V. C. Kelley, and A. J. MacAlpin. *U. S. Geol. Survey Prelim. Map 81*, Oil and Gas Inves. Ser. (March, 1948). Sheet, 42 X 58 inches. Scale, 1 inch equals 1 mile. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, \$1.00.

ENGLAND

*"A Revision of the Genus *Pentamerus* James Sowerby 1813 and a Description of the New Species *Gypidula bravonium* from the Aymestry Limestone of the Main Outcrop," by Frances Elizabeth Somerville Alexander (née Caldwell). *Quar. Jour. Geol. Soc. London*, Vol. 103, Pt. 3 (London, January 31, 1948), pp. 143-61; 10 figs., 1 pl.

*"Some English Cretaceous and Eocene Hexacorals," by Henry Dighton Thomas. *Ibid.*, pp. 163-70; 2 pls.

FLORIDA

*"Exploration for Oil and Gas in Florida," by Herman Gunter. *Oil*, Vol. 8, No. 1 (New Orleans, March, 1948), pp. 14-16; 1 map.

FRANCE

*"Nomenclature stratigraphique du Crétacé inférieur dans le Sud-Est de la France" (Lower Cretaceous Stratigraphic Nomenclature in Southeastern France), by M. Gignoux and L. Moret. *Travaux Lab. Geol. Univ. Grenoble*, Vol. 25 (Grenoble, 1946), pp. 59-88. French.

*"Le gisement de gaz combustibles naturels de Saint-Gaudens, Haute-Garonne" (Natural Gas at Saint Gaudens), by M. Maurice Gignoux. *Procès-Verbaux Mensuels Soc. Sci. Dauphine*, Vol. 24, No. 188 (Grenoble, November, 1945), 5 pp. French.

GENERAL

*"The Oil Shale Deposits of the World and Recent Developments in Their Exploration and Utilization, Reviewed to May, 1947," by W. H. Cadman. *Jour. Inst. Petroleum*, Vol. 34, No. 290 (London, February, 1948), pp. 109-32; 2 photographs of plant at Rifle, Colorado.

*"Wave Action on Structures," by Walter H. Munk. *Petrol. Tech.* (New York, March, 1948), 18 pp., 16 figs., 2 tables. *A.I.M.E. Tech. Pub.* 2322.

*"Planning a Multiple Well Directional Drilling Program for Offshore Locations," by John G. Jackson and J. B. Murdock, Jr. *Ibid.* 20 pp., 10 figs. *Tech. Pub.* 2325.

*"New Mississippian Stratigraphic Names," by J. Marvin Weller. *Amer. Jour. Sci.*, Vol. 246, No. 3 (New Haven Connecticut, March, 1948), pp. 150-51.

*"Major Tectonic Phenomena and the Hypothesis of Convection Currents in the Earth," by Felix Andries Vening Meinesz. *Quar. Jour. Geol. Soc. London*, Vol. 103, Pt. 3 (London, January 31, 1948), pp. 191-207; 5 figs., 1 pl.

*"Report on the Oil Situation," by Max W. Ball. Digest of testimony given before committees of the House of Representatives. *Com. Interstate and Foreign Commerce*, Hon. Charles A. Wolverton, chairman, December 12, 1947, January 29, 1948. 60 mim. pp.

*"Proceedings of Joint Conference of Committee on Geologic Education and Association of Geology Teachers," M. King Hubbert, chairman. *Interim Proc. Geol. Soc. America*, Pt. 2 (New York, March, 1948). 37 pp.

GULF COAST

*"Engineering Characteristics of the Gulf Coast Continental Shelf," by M. B. Willey. *Petrol. Tech.* (New York, March, 1948). 11 pp., 2 figs., 9 tables. *A.I.M.E. Tech. Pub.* 2323.

IOWA

"Geologic Map Index of Iowa," compiled by Leona Boardman and Annabel Brown. One of a series of titles "Index to Geologic Mapping in the United States." For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, \$0.35.

KANSAS

*"Geology and Ground-Water Resources of Seward County, Kansas," by Frank E. Byrne and Thad G. McLaughlin. *Kansas Geol. Survey Bull.* 69 (Lawrence, March, 1948). 140 pp., 12 pls., 10 figs., 10 tables.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 22, No. 2 (March, 1948).

"Applied Micropaleontology in Coastal Ecuador," by R. M. Stainforth.

"Foraminifera from the Porter Shale (Lincoln Formation), Grays Harbor County, Washington," by Weldon W. Rau.

"Foraminifera from the Middle Neocomian of the Netherlands," by A. ten Dam.

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1946" by Hans E. Thalmann.

"*Manorella*, a New Genus of Foraminifera from the Austin Chalk of Texas," by Charles R. Grice.

"Intraspecific Categories in Invertebrate Paleontology," by Norman D. Newell.

"Fossil Tintinnids: Loricated Infusoria of the Order of the Oligotricha," by G. Colom.

"Paleontologist—Biologist or Geologist?" by Norman D. Newell and Edwin H. Colbert.

"Paleontologist—Biologist and Geologist," by J. Marvin Weller.

THE ASSOCIATION ROUND TABLE

ARVILLE IRVING LEVORSEN, SIDNEY POWERS MEMORIAL MEDALIST

ARTHUR E. BRAINERD¹
Denver, Colorado

In recognition of distinguished and outstanding contributions to, and achievements in, petroleum geology, The American Association of Petroleum Geologists presented to Arville Irving Levorsen, a widely known petroleum geologist and Dean of the School of Mineral Sciences of Stanford University, its highest honor, the Sidney Powers Memorial Medal Award. This honor was conferred at the 33d annual meeting of the Association in Denver on April 27, 1948, by C. E. Dobbin, president of the Association. Levorsen is the third member of the Association to receive this award.

Levorsen was born on July 5, 1894, in Fergus Falls, Minnesota, son of Levor Anson and Laura Larsen Levorsen. He attended secondary schools in his home city. In 1913 he entered the University of Minnesota School of Mines and received a degree of Mining Engineer in 1917. He was awarded an honorary degree of Doctor of Engineering from Colorado School of Mines in 1942. In 1947, on the 30th anniversary of his graduation, the University of Minnesota awarded him a degree of Doctor of Science.

In March, 1920, Levorsen married Elma Hario. They have four children; Jean Marguerite, Robert Irving, James Kingdon, and John Anson.

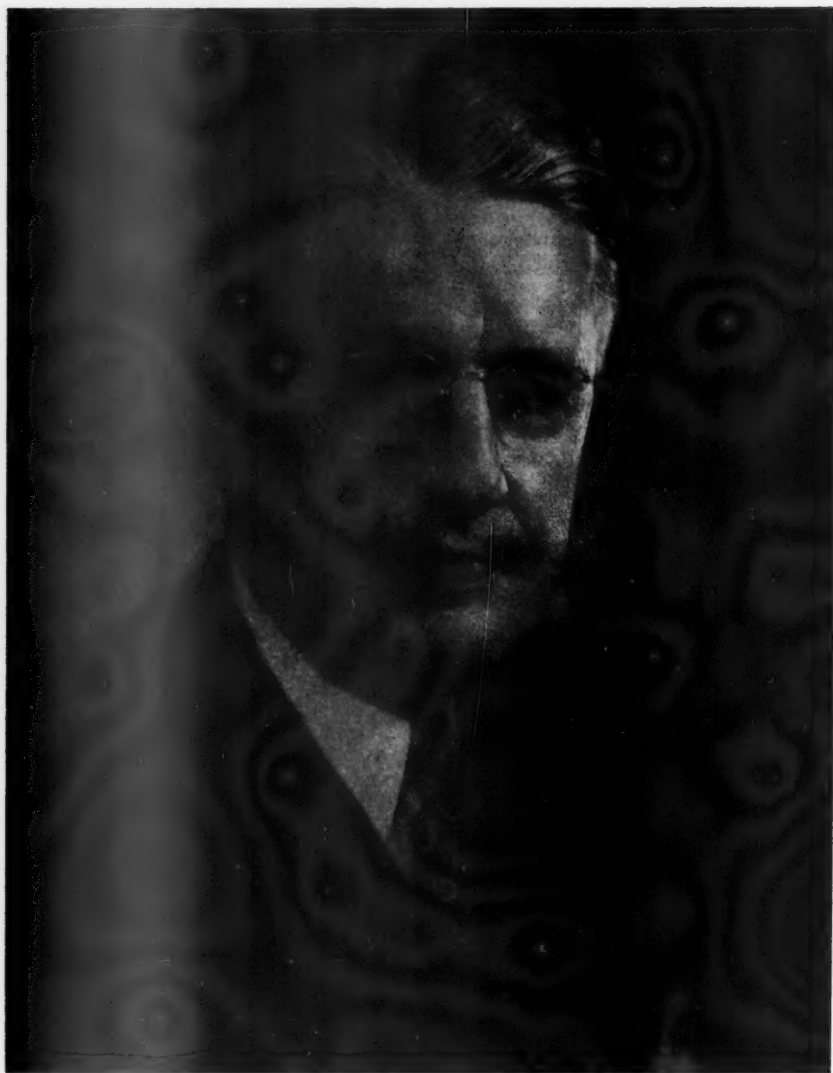
Following his graduation from the Minnesota University School of Mines in 1917, Levorsen started to work as a field geologist for the Greenwood Company in Kansas. In February, 1918, he enlisted in the 27th Engineers (Mining) U. S. Army. Following a service of sixteen months, part of which was in Europe, he received his discharge in May, 1919. Following his discharge, he again started geological work and until 1926 he was geologist with the Greenwood Company, Getzandaner and Johnston, and the Gypsy Oil Company. From 1926 to 1930 he was chief geologist for the Philmack Company and the Independent Oil Company. For the next four years he was a consulting geologist, and from 1934 to 1936 he was chief geologist for the Tide Water Oil Company. In 1936 Levorsen resigned from the Tide Water to enter consulting work in Tulsa. He remained as a consulting geologist until 1945 when he accepted the chairmanship of the geology department at Stanford University, Palo Alto, California. In 1947 he was appointed Dean of the School of Mineral Sciences at Stanford, a position he now holds.

He has rounded out thirty years of geological work, the greater part of it in geology as applied to the finding of petroleum. In his company work he was a successful oil-finder and as an executive he has a record as an inspiring leader.

In 1932 and 1933, as a consulting geologist, Levorsen worked out the structure and recommended the drilling of the Fitts pool in the Franks graben, Pontotoc County, Oklahoma. This discovery stands as a monument to his sound reasoning as applied to the discovery of petroleum. It took courage to recommend this project at the particular time, but Levorsen had the courage of his convictions and the result is history.

Levorsen joined The American Association of Petroleum Geologists in 1919, two years after it was founded. He has been outstanding in the organization, no one more so, and thus has taken a very important part in the Association's amazing development. He has given unlimited time and effort to the organization, acting as chairman of important

¹ Continental Oil Company.



ARVILLE IRVING LEVORSEN

committees and as the Association's president in 1935-1936. He was the Association's representative to the National Research Council from 1940 to 1944. He was editor of "Possible Future Oil Provinces of the United States and Canada" published in the *Association Bulletin*, Vol. 25, No. 8 (August, 1941), also of *Stratigraphic Type Oil Fields* published as a symposium by the Association in 1941. He has written fifteen or more of what may be termed major articles for publication in the *Bulletin*.

His thinking has always been of a forward and creative type, to an end of adding something new and useful in petroleum exploration. The development of his ideas is best illustrated by citing chronologically a few of his publications: "Convergence Studies," 1927; "Pennsylvanian Overlap in the United States," 1931; "Stratigraphic Versus Structural Accumulation," 1936; "Application of Paleogeology to Petroleum Geology," 1938; "Discovery Thinking," 1943; and "Time of Oil and Gas Accumulation," 1945.

For several years Levorsen has lectured widely to university students, academies of science, Government agencies and committees, and to many other groups. Certainly no one has done more than he to further the interests of petroleum geology and of The American Association of Petroleum Geologists, from a national standpoint. There are few geologists in the petroleum industry whose exploratory thinking has not been influenced by his publications and talks.

Levorsen's interest in geology has been broad and not confined entirely to the petroleum industry. He became a member of the Geological Society of America in 1930. He was a councilor from 1942 to 1946 and served on the following committees:

Membership: 1942 to 1944, 1946
Geological Map of South America: 1942-1946
Finance: 1943
Geological Institute (delegate): 1944-1945, 1946
Research: 1945.

He was vice-president in 1946, and president in 1947. He is also a member of the following societies:

Society of Economic Geologists (councilor, 1941-1944)
Society of Economic Paleontologists and Mineralogists
American Institute of Mining and Metallurgical Engineers
American Association for the Advancement of Science.

Levorsen's professional standing as a scientist is internationally known and recognized as of the highest order. In his present position as Dean of the School of Mineral Sciences at Stanford University, he should have opportunity to continue and expand his already impressive record in petroleum geology. His kindly nature and sterling character, added to his knowledge and wealth of experience in geology, will have a profound effect on the succeeding generation of young geologists who pass through his department, and on others with whom he will come in contact. His influence will long be felt and when these times are history, the name of Arville Irving Levorsen will stand high among the geologists of all times.

MAJOR ARTICLES BY ARVILLE I. LEVORSEN

- "Convergence Studies in the Mid-Continent Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 7 (1927), pp. 657-82.
"Oil and Gas in Oklahoma; Geology of Seminole County," *Oklahoma Geol. Survey Bull.* 40-BB (1928).
"Greater Seminole District, Seminole and Pottawatomie Counties, Oklahoma," *Structure of Typical American Oil Fields*, Vol. 2 (Amer. Assoc. Petrol. Geol., 1929), pp. 315-61.
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HUGH DINSMORE MISER, HONORARY MEMBER¹

ROBERT H. DOTT²

Norman, Oklahoma

In northeastern Benton County, not far from the northwest corner of Arkansas, and extending a short distance into Missouri, is an area of high land lying between Big and Little Sugar creeks. This high country is known as Pea Ridge, on the south flank of which stands a village of the same name. Pea Ridge is notable because of two historic events, the earliest of which was a little-known, but very decisive battle between the Union and Confederate armies during the Civil War; the second was the birth of Hugh Dinsmore Miser, in Pea Ridge village, on December 18, 1884, to Jordon Stanford and Eliza Caroline (Webb) Miser.

Hugh's boyhood was spent in this small, rural community, where he attended the local schools. He was introduced to geology in a small way by a high school science teacher, and at the University of Arkansas he came under the influence of A. H. Purdue. The youth's inherent traits, the exceptional facilities of the outdoor laboratory in the vicinity of Fayetteville, and Purdue's inspiration combined to produce one of the most zealous geologists of our generation.

¹ Manuscript received, March 6, 1948.

² Director, Oklahoma Geological Survey.

There are a number of localities in the world whose soil, so to speak, seems to be peculiarly rich in elements that nurture and develop geologists. For example, the region around Cincinnati, Ohio, is famous for the large number of eminent geologists and paleontologists who received their inspiration in that classic paleontologic area.



HUGH DINSMORE MISER

Northwestern Arkansas deserves some recognition in this connection, especially by Oklahoma geologists. While Hugh Miser was a very small boy, N. F. Drake, also a native of northwestern Arkansas, and J. A. Taff, a native of Tennessee, were engineering students at the University of Arkansas. The contributions of this trio to the basic understanding of Oklahoma geology has been tremendous.

Some geneticists lay great stock on the influence of environment in shaping a person's physical and mental development. The geological environment of northwestern Arkansas appears to support this hypothesis with respect to these three men, and the Oklahoma angle of their common development merits further consideration. It may or may not be of significance that Summers, the birth place of Drake, Pea Ridge, and Fayetteville lie west of the extremely narrow divide between White River, which drains eastward across Arkansas, and tributaries of the Grand and Illinois rivers, which drain into Oklahoma. Perhaps the geological interest of these men followed the drainage.

This interesting theory may be further amplified by reference to one of the numerous stories for which the subject of this talk is famous: "In Arkansas," says Miser, "we had a mule, and do you know, by jiggers, that mule didn't want to do anything but go to Oklahoma."

Early in the century, the United States Geological Survey made considerable use of geology professors over the country, and Purdue undertook extensive investigations of the Paleozoic areas of western Arkansas. Working under cooperative arrangements between the Federal and State surveys, he utilized his more promising students as field assistants, obtaining for them temporary appointments as geologic aids. Hugh Miser received such an appointment in 1907, and during the ensuing 5 summers assisted Professor Purdue in geological investigations of the Ouachita Mountains.

Miser has reported that he was reimbursed for his modest field expenses, and in addition, received to start with, the munificent wage of one dollar per day from the State of Arkansas, earning a total of \$8.00 during the latter part of June, 1907. Through Purdue's arrangement, on July 1, he became Geologic Aid on the Federal Survey, and to his great delight, received 100 per cent increase in salary—the greatest of his entire career.

While still in State employ, Miser was very much annoyed to have a notary public in a small mountain town exact half a day's pay for acknowledging some official document. Government red tape has hounded him and irritated him ever since, and in later years, has led him to seek by-passes, frequently at his own expense. In not a few instances he has paid junior employees out of his own pocket for services rendered, because cumbersome official procedure made it very difficult or impossible for the young employee to collect in reasonable time through regular channels.

Miser's first professional work was not easy, and might have discouraged a less hardy and less determined young geologist. The terrain was very difficult, extremely rough and heavily timbered. The geologists travelled on horseback and afoot, mostly afoot, and their eating and sleeping depended much of the time on the hospitality of the mountaineers. Professor Purdue, in the preface to a report entitled "The States of Arkansas," published in 1909 by the Arkansas Geological Survey, paid the following tribute to his assistants:

As associates with the writer in the field work, were Messrs. R. D. Mesler and H. D. Miser, recently students in the department of Geology, University of Arkansas. Whatever value there may be in this report is largely due to the efficient work of these two gentlemen, who never shrank from the arduous task of constant, difficult mountain climbing beneath the hot rays of the sun.

I can testify from personal experience that forty years have dimmed neither Hugh Miser's enthusiasm nor his energy for climbing mountains to see what's on top, or on the other side.

The four years following Miser's graduation in 1908 included field work in Arkansas as Purdue's assistant, and on his own; marriage to Mary Kate Goddard, of Fayetteville, on September 21, 1910; appointment as Junior Geologist on the staff of the United States Geological Survey in 1911; receipt of the Master's degree and advancement to the grade of Associate Geologist in 1912. His career was definitely launched.

In 1912, Purdue moved to Tennessee to become State Geologist, a position which he held until his death in 1917. At different times during Purdue's tenure, and probably at

his suggestion, Miser was assigned by the Federal Survey to cooperative projects in Tennessee and he prepared several reports on mineral resources and areal geology of parts of that state.

Other assignments covered investigations of a variety of economic minerals, including bauxite, diamond-bearing peridotite, gypsum, gravels, asphalt, and oil possibilities, but his major projects were areal mapping, in which he became very proficient. During World War I, and again in the early stages of World War II, Miser did considerable work on manganese deposits in Arkansas, Tennessee, Virginia, and elsewhere.

In 1919, he was advanced to the grade of Geologist on the Federal Survey, and during the school year of 1919-1920 he returned to Fayetteville, where he was Acting Professor of Geology, and Acting State Geologist.

Excepting the brief sojourns in Tennessee and Virginia, the greater part of Miser's work during the period 1907-1920 was in Arkansas, and is recorded in major reports on the Eureka Springs-Harrison Quadrangle, DeQueen-Caddo Gap Quadrangle, Hot Springs Quadrangle, and the Batesville district, Arkansas. To this list should be added a report on the Waynesboro Quadrangle, Tennessee, and more than a dozen minor publications on various subjects. The early and intensive concentration on the Ouachita Mountains created an interest in the geology of that area that has grown through the years, and that runs like a brightly colored thread through his subsequent writings.

In the summer of 1921, Miser's attention was transferred to a new terrain and new experiences, as a member of the Trimble party which descended the San Juan River in Southeastern Utah, in a canyon voyage that rivaled the experiences of Major Powell and his parties through the Grand Canyon of the Colorado, 50 years earlier. Miser is the author, or joint author, of nine papers that were based on information obtained on this trip, and the variety of subjects discussed testifies to his alertness and powers of observation. The major report authored by Miser alone, is entitled "The San Juan Canyon, Southeastern Utah, a Geographic and Hydrographic Reconnaissance," published as United States Geological Survey *Water Supply Paper 538* (1924). This fascinating report is recommended highly to fireside adventurers and armchair explorers.

The members of this party had few dull moments despite the fact that they were cut off from the outside world for $2\frac{1}{2}$ months. There was the swift river with many hazardous rapids; narrow canyons with sheer walls hundreds of feet high that had to be climbed; geological observations as far as 25 miles away from the river; soakings in torrential rains; a side trip to Rainbow Natural Bridge. These were only a few of the experiences.

Purdue, in his tribute to the zeal of Miser and Mesler failed to report ticks and other insects among the hardships of the work. Miser, however, writes eloquently of the insect life of the San Juan country:

Several kinds of insects, especially flies, mosquitoes, ants, and scorpions proved to be far too numerous for comfort. The thousands of ants that inhabit the sand bars on which we slept were bedfellows on many occasions, and they always displayed two disagreeable traits—crawling and biting. On a few occasions scorpions who were bedfellows were crowded too much and expressed their anger by stinging. . . .³

Though assignments during the next few years were more or less routine, they did involve contributions to several works on petroleum, including the Fourth Edition of Sir Boverton Redwood's *Treatise on Petroleum*.

We come now to the point in Hugh Miser's career when he became known to practically every Oklahoma geologist. The decade beginning with World War I was one of great activity in exploring for oil in Oklahoma, and an incredible amount of surface mapping was done during this period. Few areal maps were in existence, especially for the area

³ Hugh D. Miser, "The San Juan Canyon, Southeastern Utah, a Geographic and Hydrographic Reconnaissance," *U. S. Geol. Survey Water-Supply Paper 538* (1924), p. 20.

being explored most intensively, and most geologists had little idea of the names, ages, or correlation of the rocks with which they were working. The Oklahoma Geological Survey had been contemplating the compilation of a general map, but one of Oklahoma's colorful governors put a stop to that and other things by vetoing the Survey's appropriations.

The need was so great that the late Sidney Powers called on geologists working in the state for contributions to finance a cooperative project whereby a geologist of the Federal Survey could be assigned. Hugh Miser was that geologist, and in July, 1923, he began the huge task. With his striking clarity of vision, he saw that success of the undertaking depended almost wholly on the cooperation, good will, and understanding of the geologists and officials of the petroleum industry. Owing to the paucity of published data, access to oil-company files was essential if the kind of map desired was to be prepared.

His tact, skill, and understanding of local industry problems led to unqualified success and established a new pattern of cooperative effort between the oil industry and the Federal Survey. The energetic, efficient, discriminating, and highly discreet manner in which he utilized confidential files of oil companies, and the good-natured and eminently fair manner in which he resolved controversial questions, earned him the undying respect and deep affection of Oklahoma geologists.

In 1926, Miser took leave of absence from the Federal Survey to accept appointment as State Geologist of Tennessee, but this was not greatly to his liking, and after one year he returned to Washington to become Chief of the Survey's Section of Areal Geology.

In 1927 he returned to Oklahoma for a brief field season, the results of which proved to be one of Miser's greatest scientific contributions. To quote his words:⁴

... The suggestion was offered some years ago by Dake that the rocks of the Ouachita Mountain region were thrust northward a long distance over rocks that have the same facies as those of the Arbuckle Mountains near-by to the west. But it was not until 1927 that the presence of low-angle thrust planes in the Ouachita Mountains was proved by field observations. In that year I discovered a window through an overthrust mass in and near Round Prairie, in the Potato Hills, west of Tahihina, Oklahoma. This window ... not only leads to the conclusion that low-angle thrusts exist in the Ouachita Mountains but supports the suggestion of Powers that the numerous major parallel faults in the mountains bound thin slices of the earth's crust.

The present paper gives the first published picture of the geologic structure of the entire Ouachita Mountain region. It is based in large measure on field data that I have obtained during all or parts of fourteen field seasons, beginning in 1907. Most of the field seasons were spent in the Arkansas portion of the region. No opportunity came for spending much time in the Oklahoma portion until 1927, when field studies were extended to all the mountain areas that I had not previously visited. Thus it was not until this year that I was able to gain a complete structural picture of the entire region.

My own field results are necessarily combined, to a large extent, with those of other geologists, who have made stratigraphic and structural studies of the region. These geologists include Griswold, Ashley, Taff, Wallis, Honess, and the late Professor Purdue. In fact, I worked for several years (1907-1911) as an assistant to Purdue, a devoted teacher, to whom I owe much of my training in geology.

Proof of low-angle thrusts, through discovery of the Potato Hills window was highly significant, because it opened new lines of thought in interpretation of Ouachita Mountains geology, and the important role of overthrusting in the orogeny of the region is now generally recognized by all geologists who have worked there since 1927. In May, 1947, on a field trip in the northwestern Ouachitas, sponsored by the Tulsa Geological Society, Miser had the satisfaction of seeing his basic ideas demonstrated by T. A. Hendricks and others, and accepted by the 168 geologists on the trip.

At a stop in the Potato Hills, Miser entertained the group with an account of his field work when he discovered the existence of the window. It seems that Oklahoma was visited by one of its phenomenal rainy seasons, and the roads from Tahihina being impassable, he was forced to walk from town. Round Prairie was a lake, the streams were all out of their banks, and fish were swimming in the streets of Tahihina. He left the impression, perhaps unintentionally, that the fish greatly impeded his walking expeditions.

⁴ Hugh D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull.* 50 (1929), pp. 5-6.

Though Miser has gained a great liking for Oklahoma geology and Oklahoma geologists, there are some things about the state that have not impressed him so favorably. For example, the day in July, 1923, when he reached Tulsa for beginning work on the geologic map, the Governor declared martial law. His first official act on reaching Norman in September, 1947, to begin work on the revision of the map, was to visit the police station for the purpose of being finger-printed. However, he can not blame Oklahoma for this, because he was acting under instructions from the FBI in connection with the loyalty check of Federal employees.

The thing that seems to irk him most about Oklahoma, however, is what he calls "fried chicken, Oklahoma style"—a neck, a back, and two wings.

In July, 1927, Miser was appointed Chief of the Section of Fuels, a position which he held with distinction for 20 years. To this new task he brought a shrewd understanding of personnel problems, unrelenting diligence, a keen faculty for reviewing organization and preparation of reports, and profound knowledge of stratigraphic nomenclature. Most of all, however, through his rich experience in compiling the Oklahoma map, he brought to the new job a background of knowledge of conditions under which oil-company work is done, and an understanding of the desires and needs of the petroleum industry. He was thus able to set a course for the work of the Fuels Section that became increasingly important and helpful to the petroleum industry.

Under his leadership, a small group of geologists, thoroughly indoctrinated with his diligence, accuracy, and sound approach to geologic research, produced a series of substantial contributions to the geology of fuels. It is through Miser's long and effective service as Chief of the Fuels Section, and his activity as a member of this Association as author, Associate Editor, and worker on numerous committees, that most petroleum geologists know him.

Early in the period of uncertainty preceding World War II he was one of the first to realize that the national interest demanded all-out effort toward locating and developing deposits of minerals likely to be in critically short supply. Despite his personal interest in the field of the mineral fuels, he diverted nearly his entire staff to work on strategic and critical minerals, cutting short projects of his own Section on which field work had actually begun. During this period he was for a time in charge of manganese investigations and served as regional geologist of the Geological Survey for the eastern United States.

He also pointed out the possibility of obtaining much-needed oscillator quartz for radio and radar, from Arkansas quartz crystals. He trained himself in the recognition of satisfactory crystals, and by combing his own large collection and by visiting dealers in the Hot Springs area, he gathered together several pounds of satisfactory material. Later he recommended localities for mining operations, and directed geological prospecting parties. Though this venture was not an impressive success, it did yield a small amount of quartz to supplement the imports from Brazil.

As the war progressed, demands for petroleum products increased beyond all expectation, and official Washington felt the need for governmental activity in this field. In July, 1943, a special appropriation was made by Congress for work on petroleum. Characteristically, Miser saw that the kind and place of work must have the approval and support of the petroleum industry and State agencies; and that the results, to be of value, must be released in the most expeditious manner possible.

During an arduous tour of the country, conferring with hundreds of petroleum geologists, State geologists, and officials of educational institutions, it was decided that the work should emphasize regional geology involving both surface and subsurface stratigraphy. As a result, the studies were devoted primarily to the accumulation of data pertaining to correlations, changes of facies in oil-producing formations, margins of producing areas, and relation and extent of lenticular sands. These studies were to have as their objective the delimitation of broad areas favorable for exploration.

This emergency war-time oil and gas investigation will stand for many years as an

outstanding example of how a governmental scientific agency, under intelligent leadership, can approach and prosecute a program of work vital to the national interest, with efficiency, and without unnecessary duplication of, or conflict with, either private industry or State agencies. Recalling the activities of many war-swollen Federal agencies, this is indeed worthy of more than passing note, and to Hugh Miser goes much of the credit.

Even in the hectic days of war and preparing for war, Miser could find time to write papers. His address as Retiring Vice-President of Section E, of the American Association for the Advancement of Science in 1941, entitled "Quartz Veins in the Ouachita Mountains of Arkansas and Oklahoma," embodied a profound insight into, and a new approach to, the geologic history of that region. It brought together all lines of evidence, and included a clever capitalization of his chief hobby—collecting quartz crystals.

The following quotations from this address are characteristic of the man and the scientist.⁵

Each geologic feature of an area, whether it be a quartz-vein crystal, an anticlinorium, a grahamite deposit, a coal bed, an igneous rock, or a metalliferous deposit, is related to all the other geologic features of the area. The full narration of the geologic history of an area is, in reality, a fascinating connected story in which each and every geologic feature plays a part. An important chapter of the geologic history of the Ouachita Mountains is that revealed by quartz veins and crystals. . . .

The several geologic problems that have been discussed in the foregoing address are trails along which I have been led by my hobby, the collection of Arkansas quartz crystals. The delivery of this address today does not mean that I shall now stop and dismount from my hobby. Instead, I intend to continue the collection of Arkansas quartz crystals as long as I am an Arkansas traveler and can obtain funds and credit for the purchase of quartz crystals from the dealers occupying the roadside stands in western Arkansas.

Hugh Miser holds membership in the following scientific societies.

American Association for the Advancement of Science, Vice-President, Section E, 1940
 American Association of Petroleum Geologists, in which he has served on the Business Committee, 1928-1931; Geologic Names and Correlations Committee, 1929-1948; Medal Award Committee, 1943-1947; Method of Election of Officers, 1944-1945; and Associate Editor, 1932-1948
 American Institute of Mining and Metallurgical Engineers
 Geological Society of America
 Geological Society of Washington, President, 1938
 Mineralogical Society of America
 Society of Economic Geologists
 Society of Economic Paleontologists and Mineralogists
 Tennessee Academy of Science
 Tulsa Geological Society, Honorary Member
 Washington Academy of Science, Vice-President, 1939
 Acting chairman and chairman, Geologic Names Committee, United States Geological Survey, December 26, 1930, to February 4, 1947
 Director, Sibley Memorial Hospital, Washington, 1925-1944; Chairman of the Board, 1936-1937
 Listed in *Who's Who* and *American Men of Science*

Hugh Miser at his own request, retired as Chief of the Fuels Section on July 1, 1947, after exactly 20 years of service. Relieved of administrative details, free of the self-imposed necessity of long hours of overwork, he once more has time and opportunity to pursue his interests in solving knotty geological problems. It is very gratifying to Oklahoma geologists that his first job is the revision of the Geologic Map of Oklahoma.

It is a great pleasure to me to have a small part in honoring to-day a man who in our times, through his own work as a geologist, as a planner and administrator of the work of others, and as an active worker in this Association, has contributed so greatly to the development of petroleum geology.

⁵ Hugh D. Miser, "Quartz Veins in the Ouachita Mountains of Arkansas and Oklahoma, Their Relations to Structure, Metamorphism, and Metalliferous Deposits," *Econ. Geol.*, Vol. 38, No. 2 (March-April, 1943), pp. 117, 118.

LAURENCE L. SLOSS AND WILSON M. LAIRD, RECIPIENTS
OF PRESIDENT'S AWARD¹CHARLES E. ERDMANN²

Great Falls, Montana

The President's Award for 1947 was presented with appropriate ceremony on April 27, 1948, during the annual meeting at Denver, Colorado, to Laurence L. Sloss and Wilson M. Laird, for their joint article, "Devonian System in Central and Northwestern Montana," published in the August, 1947, *Bulletin* of the Association.

This was the fourth presentation of this award, which was instituted in 1944, during the presidency of Ira Cram; and it is the first time that it has been presented to co-authors. The award consists of \$100 in cash with a suitably worded certificate of award. According to the rules, "In case an article is selected having joint eligible authors the monetary award shall be divided among the authors and duplicate certificates of award shall be presented."³ The purpose of the award is to honor and reward the younger authors of original articles published in the *Bulletin* of the Association during each calendar year as a means of stimulating research activity and authorship in their age group. Nominations for the award originate in the Medal Award Committee, who are charged with the selection of the article that, in their opinion, "makes the most significant contribution to petroleum geology," by writers who must not have reached their 35th birthday on January 1 of the year in which the paper is published.

LAURENCE L. SLOSS

Laurence Louis Sloss was born on August 26, 1913, at Mountain View (now Los Altos), California. His elementary education was received in the San Francisco public schools; and he entered Stanford University in 1930. This undergraduate work culminated in a B.A. degree from Stanford in 1934, and included two summers of field work in a Paleozoic area in Nevada. Sloss enrolled for graduate work at the University of Chicago in the fall term of 1934, and received his Ph.D. degree in geology there in 1937. His doctoral dissertation on Devonian corals was inspired by vast unworked collections in the Walker Museum; and the results of this investigation were published as, "Devonian Rugose Corals from the Traverse Beds of Michigan," *Journal of Paleontology*, Vol. 13, No. 1 (1939), pp. 52-73.

Sloss went straight from the University of Chicago to the Montana School of Mines at Butte, Montana, where an instructorship in geology awaited him. He immediately became interested in all of Montana's varied stratigraphy, particularly that of the oil fields, and soon became conversant with it in practically all phases. Eight field seasons were spent on investigations of Paleozoic rocks under the auspices of the Montana Bureau of Mines and Geology, in which he attained the rank of Geologist. The opportunity to combine work in the field with that in the classroom enriched his experience greatly. In the classroom his easy and fluent delivery, coupled with an atmosphere of convincing authority in his subject, were an inspiration to his students. He was made Assistant Professor of Geology in 1939, and promotion to Associate Professor followed in 1943. His tireless energy in the field, unique ability at critical analysis, and vivid scientific imagination soon resulted in a series of valuable articles on stratigraphy. Among the more outstanding are the following.

(with Ralph H. Hamblin), "Stratigraphy and Insoluble Residues of the Madison Group (Mississippian) of Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 3 (March, 1942), pp. 305-35.

¹ Published by permission of the director of the United States Geological Survey. Manuscript received, March 26, 1948.

² Regional geologist, United States Geological Survey.

³ Ira H. Cram, "Announcement and Rules of the President's Award," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 1 (January, 1945), pp. 118-19.

(with Eugene S. Perry), "Big Snowy Group: Lithology and Correlation in the Northern Great Plains," *ibid.*, Vol. 27, No. 10 (October, 1943), pp. 1287-1304.

(with S. R. B. Cooke), "Spectrochemical Sample Logging of Limestones," *ibid.*, Vol. 30, No. 11 (November, 1946), pp. 1888-98.

Thus was laid the foundation of stratigraphic work that was to approach culmination in his leadership of the investigation of the Devonian system in Montana, which is re-



LAURENCE L. SLOSS

viewed in the concluding section of this article. His other geologic interests include the petrology, chemistry, and associations of non-clastic sediments. Inevitably, as his reputation as a stratigrapher developed, opportunities multiplied for contacts with industry and other educational institutions. At the close of the Spring semester in 1946, Sloss severed his connection with the Montana School of Mines to accept a professorship in the Department of Geology at Northwestern University at Evanston, Illinois. The summer of 1946 was spent on stratigraphic work for the Carter Oil Company, that of 1947 with the Phillips Oil Company; both in Montana.

Sloss is a Fellow of the Geological Society of America, the Paleontological Society, and the American Association for the Advancement of Science. He is also a member of the American Association of Petroleum Geologists, American Geophysical Union, Sigma Xi, and the Yellowstone-Bighorn Research Association.

WILSON MORROW LAIRD

Wilson Morrow Laird was born on March 4, 1915, in Erie, Pennsylvania, to Charles W. and Elizabeth Morrow Laird. Much of his early youth was spent out of doors; and, at the age of twelve he was given entire charge of a small farm near Hartstown, Pennsylv-



WILSON M. LAIRD

vania, whereon cropped out rocks of Upper Devonian age. The boy soon began to collect fossils from them, although he did not know exactly what the forms represented. Not until he was studying geology in college did he learn that many of his specimens were the brachiopod *Leiorhynchus emmonsii*. Singularly enough, the study of this series and its fauna was later to constitute much of his professional interest.

Laird enrolled in Muskingum College in New Concord, Ohio, in the fall of 1932, and received his B.A. degree *cum laude* in 1936, with a major in geology. Originally, his intention had been to enter the ministry; but the influence of his early surroundings coupled with a course in General Geology during his Freshman year contributed to a change of mind as he realized he "had more enjoyment in the actual fact of saving fossils than in the possibility of saving souls." His introduction to professional geology came in the fall of 1936, with enrollment at the University of North Carolina, where he studied under W. F.

Prouty and John Huddle. The summers of 1936 and 1937 were spent with the Pennsylvania Geological Survey. During this period, material was obtained for a thesis on the Martinsburg formation in the vicinity of Harrisburg, Pennsylvania, which was accepted in partial fulfillment of a Master's degree at the University of North Carolina. Laird received this degree in 1938; but did not publish the thesis. He went on that fall to enroll at the University of Cincinnati, and, under the direction of K. E. Caster, also a Devonian specialist, investigated the Upper Devonian and Lower Mississippian of certain inliers in the Chestnut Ridge and Laurel Hill areas of the Allegheny Mountains in southwestern Pennsylvania. This problem occupied the summers of 1938, 1939, and 1940, the last summer again being spent with the Pennsylvania Geological Survey. After completing his thesis: "The Upper Devonian and Lower Mississippian of Southwestern Pennsylvania," Laird received the Ph.D. degree in geology from the University of Cincinnati in 1942. The main body of this thesis was published under this same title in *Pennsylvania Geological Survey Progress Report No. 126* (1941), 23 pages. The foundation for his Devonian studies in Montana was thus well laid.

In the fall of 1940, Laird came to the University of North Dakota as Assistant Professor of Geology. In February, 1941, he also assumed the offices of Acting State Geologist and Head of the Department of Geology, and became State Geologist that year. His progress in academic work was not quite so rapid, but he was promoted to Associate Professor in the fall of 1942, and full Professor in 1946. During the war years of 1944 and 1945, he was given leave of absence to serve on the investigation of the Montana Devonian, and ranked as an Associate Geologist on the United States Geological Survey. This latter connection is still maintained through an appointment as Geologist (w.a.c.), attached to the office of the Geological Survey at Great Falls, Montana. His professional experience has been exceptionally broad, and, in addition to saving fossils (paleontology), includes work in the fields of stratigraphy, geomorphology, and economic geology, the latter including both oil and gas as well as underground water.

Laird is a Fellow of the Geological Society of America and the Paleontological Society. He is also a member of the American Association of Petroleum Geologists, the American Institute of Mining and Metallurgical Engineers, the Association of American State Geologists, Sigma Xi, and the North Dakota Academy of Science. Laird is also active in Boy Scout work in Grand Forks and is Assistant Scoutmaster of Troop 18 of the Presbyterian Church, and Council Advancement Chairman for the Lake Agassiz Council.

Laird's bibliography at this writing consists of forty-four titles, and is thus too extensive to list. Three papers deal with his early work on the Devonian in Pennsylvania; 26 titles treat of the geology of North Dakota, and for the most part have been published through the medium of the North Dakota Geological Survey; five are on the Devonian of Montana; seven concern matters of the Association of State Geologists; and three may be described as miscellaneous.

SIGNIFICANCE OF THE PAPER

Sloss and Laird's paper on the "Devonian System in Central and Northwestern Montana" stands as a significant contribution to petroleum geology because it clarifies and refutes some important misconceptions of the geology of the Devonian that were on the verge of general acceptance, provides correlation for numerous scattered showings and traces of oil and gas that had been found in wells drilled into the Devonian, and furnishes a firm but elastic framework in both space and time for the continued investigation of the system in Montana and adjoining regions. In view of the recent discovery of the large and important LeDuc oil field in Alberta, the establishment of such a background is timely indeed.

Devonian rocks were first recognized in Montana by A. C. Peale⁴ in 1893, and by 1899

⁴ A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U. S. Geol. Survey Bull.* 110 (1893), pp. 25-32.

W. H. Weed⁵ had extended Peale's simple nomenclature as far north as the Little Belt Mountains. In the 45 years that followed no further work was done, although, following the discovery of the Kevin-Sunburst oil field in 1922, many geologists appreciated that further stratigraphic refinement was possible, and that the then standard Devonian nomenclature could be applied in the Sweetgrass arch region only with difficulty. At the end of the year 1943 only 32 deep tests had penetrated to Devonian rocks in Montana. Even today the number is but 42, and only 18 tests have been drilled through the Devonian into older formations. Practically all of these tests have been made on surface structural features, so their distribution is very irregular, exceedingly sparse, and without relationship toward the delineation of Devonian stratigraphy. Most of them have been logged poorly, and formation samples are available from only a few. No wonder that concepts of Devonian stratigraphy in Montana were confused and inadequate, and that through lack of knowledge many oil companies and individual geologists were so prejudiced against its possibilities for petroleum that they refused to countenance its exploration! Such was the situation at the time Sloss and Laird began their investigation.

The project for the investigation of the Devonian system in Montana originated as part of the oil-search program of the United States Geological Survey during World War II, and was carried out in full cooperation with the Bureau of Mines and Geology of the State of Montana. Because of his previous work on Paleozoic formations in Montana and background of Devonian paleontology, Sloss' services were contributed by the Bureau of Mines and Geology; and, likewise, because of his familiarity with Devonian paleontology and stratigraphy in the eastern States, Laird was selected to represent the Geological Survey. The training and experience of the party was thus unusually able and well balanced.

Field work began in 1944, in the rugged Primitive Area of the upper basin of the South Fork of Flathead River, one of the most remote and famous big-game regions in North America. Access was by pack train; and supplies were flown in to Forest Service landing strips. The lithologic succession and continuity of the subdivisions of the strata were established by measuring eight detailed sections extending from the east flank of the Swan Range to the Rocky Mountain front. Usually, composite samples were collected from each 5 feet of stratigraphic interval in each section, and crushed to simulate well cuttings for microscopic examination. Cuttings and cores were then examined from five deep tests on the Sweetgrass arch. The results of this study and comparison were incorporated in a preliminary correlation chart.⁶ In the season of 1945, ten more stratigraphic measurements were made, mostly in uplifts on the plains of central Montana, but including A. C. Peale's type Devonian section near Three Forks; and sample logs were made for two more deep tests. A second correlation chart was then prepared.⁷

Restudy of the data embodied in these charts, 18 measured sections and 7 sample logs, furnished the substance for the medal-winning paper; and the serious student of the Montana Devonian will want to have them at hand as he reads and re-reads the article. Despite the intricacies of the stratigraphy, the paper is noteworthy for its lucidity and simple organization. This has been achieved by treating the Devonian lithology in terms of three separate areas or provinces: (1) the Three Forks district in southern Montana; (2) the central Montana area; and (3) northwestern Montana. The major stratigraphic units of each area are defined briefly and discussed clearly; and additional information is furnished by means of a detailed stratigraphic section for each province. In central Mon-

⁵ W. H. Weed, "Geology of the Little Belt Mountains, Montana," *ibid.*, 20th Ann. Rept., Pt. III (1899) pp. 287-89.

⁶ Laurence L. Sloss and Wilson M. Laird, "Mississippian and Devonian Stratigraphy of Northwestern Montana," *U. S. Geol. Survey Prelim. Chart 15*, Oil and Gas Inves. Ser. (1945).

⁷ Laurence L. Sloss and Wilson M. Laird, "Devonian Stratigraphy of Central and Northwestern Montana," *U. S. Geol. Survey Prelim. Chart 25*, Oil and Gas Inves. Ser. (1946).

tana they are, in order of increasing age: the Three Forks formation, predominantly shale; the Jefferson formation, composed of an upper dolomite member, including some anhydrite, underlain by dense limestone; and an unnamed basal unit of shale and shaly dolomite. These terms, as well as another previously suggested nomenclature, are inapplicable in northwestern Montana. Hence, the beds there were divided arbitrarily in descending order into: Unit A, dolomite and anhydrite, or evaporite solution breccia; Unit B, dense limestone; and Unit C, red shale and shaly dolomite. The restraint shown in postponing a third nomenclature until more complete information is available from further areal and stratigraphic work is most commendable. Age and correlation of the units are then considered; and the paper concludes with a short discussion of petroleum possibilities in the Devonian.

Among the more significant practical conclusions, the following may be noted.

1. The Devonian rocks of Montana are of Upper Devonian age (p. 1427).
2. Devonian sedimentation in Montana was divided into two basins separated by a minor positive area trending east across the central part of the state. The basin on the south was minor; that on the north very large, extending into Alberta at least as far as Edmonton (p. 1405).
3. Lithologic criteria are provided for the identification of the top of the Devonian (p. 1420).
4. Evidence for the presence of a disconformity at the base of the Devonian does not exist (p. 1420).
5. "The search for petroleum reservoirs in the Devonian of Montana has the greatest relative chance for success in the dolomite member of the Jefferson formation and the dolomites of Unit A (Potlatch anhydrite)" (p. 1428). However, "their normally occurring primary porosity and permeability do not reach high productive levels, excepting locally and unpredictably" (p. 1429).
6. The reservoirs that may be discovered, therefore, probably will be found to occur under conditions of stratigraphic traps or in areas of secondary porosity (p. 1429).

Probably every pioneer investigation raises more questions than it settles. Among the new and more specific problems of the Devonian in Montana that Sloss and Laird have recognized are the following.

1. Study of the relationships, if any, between the Potlatch anhydrite basin and the reef facies that occurs around its borders
2. Origin of the hydrocarbons that are present rather persistently in the inter-crystalline voids of the Devonian dolomites
3. Mechanics, chemistry, and time of origin of the solution breccias in the Potlatch anhydrite
4. Paleontologic revision of the *Spirifers* and *Atrypas* of the Montana Devonian
5. Further areal and stratigraphic work of the Devonian in northwestern Montana leading to a more definitive nomenclature for these strata

In view of the distinguished success of their initial assault on the basic matter of stratigraphy, let us hope that their interest and enthusiasm will remain undiminished as they turn to these additional problems.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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 Lloyd James Ryman, San Antonio, Tex.
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ARDMORE GEOLOGICAL SOCIETY FIELD TRIP, JUNE 18-19

The Ardmore Geological Society is sponsoring a field trip on June 18 and 19, covering the Pennsylvanian system of the Ardmore basin, Oklahoma. The trip will be led by C. W. TOMLINSON and JEROME WESTHEIMER, and reservations may be obtained through WALTER LACY MULLEN, Simpson-Fell Oil Company, Ardmore, Oklahoma. Immediate reservations will be appreciated.

MEMORIAL



ARTHUR SEBERT PRICE
(1904-1948)

Arthur S. Price died suddenly in Lyons, Kansas, on January 31, 1948, after an illness of only twenty hours of acute coronary thrombosis. He was born, July 2, 1904, in DeSoto, Missouri. When he was two years old he moved with his parents to Jefferson City, Missouri. His father, a native of Manchester, England, was a music instructor.

Arthur's elementary school work was completed in Jefferson City. In the fall of 1922, he entered the University of Missouri at Columbia, completing his B.A. degree in 1926 and his M.A. in 1927. He was a member of Sigma Phi Epsilon social fraternity, the Sigma Gamma Epsilon, and the Sigma Xi. After leaving the University of Missouri, a year was spent in post-graduate study in geology at the University of Chicago.

He spent his entire professional career with the Gulf Oil Corporation. His first assignment was at Seminole, Oklahoma, in June, 1928. In 1930, he was moved to the Gulf office at Wichita, Kansas, where he did microscopic and subsurface work. In May, 1936, Arthur was transferred to Chase, Kansas, where Gulf maintains a production office, and he served as geologist in that office until his untimely death.

Arthur was an accomplished musician, receiving his early training from his father. He continued his study of music at the University of Missouri, and while attending that school he was a member of the university orchestra. Due to his modest retiring nature, many of his friends did not know that he played both violin and the piano.

On June 6, 1931, Arthur married Lucille Briscoe, of Wichita, Kansas. They had one daughter, Mary Susannah, who was four years old at the time of his death. He had no brothers and sisters. His mother, Mrs. Sebert Price, lives in Jefferson City, Missouri.

Arthur was a member of the American Association of Petroleum Geologists and the Kansas Geological Society.

He was a loyal and valuable employee. He will be remembered by all who knew him for his quiet, amiable nature.

VIRGIL B. COLE

Wichita, Kansas
March 30, 1948

AT HOME AND ABROAD

NEWS OF THE PROFESSION

DISTINGUISHED LECTURE TOUR

GORDON RITTENHOUSE, associate professor of geology, University of Cincinnati, Lectured on "Interpretative Petrology of Sedimentary Rocks," before the following groups in April and May.

April	1	Pittsburgh Geological Society, Pittsburgh, Pennsylvania
	5	Ohio State University, Columbus, Ohio
	6	Illinois Geological Society, Salem, Illinois
	7	Illinois Geological Survey and University of Illinois, Champaign, Illinois
	9	Mississippi Geological Society, Jackson, Mississippi
	12	Tulsa Geological Society, Tulsa, Oklahoma
	13	Oklahoma City Geological Society, Oklahoma City, Oklahoma
	14	North Texas Geological Society, Wichita Falls, Texas
	15	Dallas Geological Society, Dallas, Texas
	16	East Texas Geological Society, Tyler, Texas
	19	Houston Geological Society, Houston, Texas
	20	Abilene Geological Society, Abilene, Texas
	22	Pacific Section A.A.P.G., Los Angeles, California
	23	San Joaquin Valley Geological Society, Bakersfield, California
May	3	University of Iowa, Iowa City, Iowa
	6	Indiana-Kentucky Geological Society, Evansville, Indiana

G. E. MANGER has joined the United States Geological Survey, Washington, D. C., after having been with the Gulf Refining Company for a number of years at Laurel, Mississippi.

CHARLES A. SHAW is a consulting geologist at Midland, Texas, where he was recently in the employ of the Forest Oil Corporation.

LESLIE BOWLING is associated with the Hunt Oil Company in New Orleans. He was formerly with William Helis.

ANDREW K. MCGILL, of the Socony-Vacuum Oil Company, has returned to 26 Broadway, from Lima, Peru.

A. M. LLOYD has resigned from the Sun Oil Company to accept the position as manager of Nelson and Edward Morris, Ltd., Dallas, Texas.

JOHN C. SPROWLE is acting exploration manager, International Petroleum Company, Lima, Peru.

J. P. DAVIDSON, of San Antonio, Texas, is division manager of the Alaska Steamship Company, 2111 Transit Tower.

RAYMOND M. LARSEN, of the United States Geological Survey at Casper, Wyoming, was in Washington, D. C., during February and March in connection with unitization hearings.

GEORGE H. CLARK, division geologist for The Texas Company, South Texas division, since February, 1947, has been made acting division manager, effective April 1. S. A. BERTHAUME succeeds him as acting division geologist and both men will continue to be located in the Houston offices.

C. W. TOMLINSON, Ardmore, Oklahoma, gave an illustrated talk on the "Proof of Coulter's Rule" at a meeting of the Shawnee Geological Society, March 18.

ARTHUR S. HUEY, formerly district geologist with Shell Oil Company, Inc., at Bakersfield, California, recently resigned and joined Hancock Oil Company at Long Beach as geologist in charge of the California area.

Appointment of ROBERT A. DREYER, associate professor of geology, as chairman of that department at the University of Kansas has been announced by Chancellor Deane W. Mallott. Dreyer succeeds L. R. LAUDON who has announced his resignation to go to the University of Wisconsin after the spring semester.

MARTIN M. SHEETS has resigned from Stanolind Oil and Refining Company to become chief geologist for the Production Maintenance Company, Houston, Texas.

KARL VER STEEG, of the department of geology and geography of the College of Wooster, Wooster, Ohio, celebrated his 25th year of service to the College this spring.

The Tulsa Geological Society was entertained at its noon luncheon, April 2, by JIMMIE C. SMITH, of the Midstates Oil Corporation, with an illustrated paper on the "Garden Grove Pool of Okfuskee and Lincoln Counties, Oklahoma."

E. J. COMBS, of the Sun Oil Company, has been elected secretary-treasurer of the Indiana-Kentucky Geological Society of Evansville, Indiana, succeeding P. L. KELLER, who has moved to Denver, Colorado.

The Houston Geological Society and the Houston Section of the Society of Exploration Geophysicists held a joint regional meeting at the Rice Hotel, Houston, Texas, March 26-27. Fourteen papers were presented on geology and geophysics.

The State Mineral Society of Texas held a mineral show at the Driskill Hotel, Austin, Texas, April 17-18.

THOMAS S. COX, independent geologist of Midland, Texas, and Irene Taylor were married at Stanford, Texas, March 12.

A. I. LEVORSEN, dean of the School of Mineral Sciences, Stanford University, California, has been chosen the recipient of the Association's Sidney Powers Memorial Medal.

ALLEN EHLERS has moved from the Tulsa office of Skelly Oil Company to Midland, Texas, to assume the duties of district geologist in charge of West Texas and New Mexico.

HUGH D. MISER, of the United States Geological Survey, has been elected to honorary membership in the Association.

L. L. SLOSS, professor of geology at Northwestern University, Evanston, Illinois, and WILSON M. LAIRD, State geologist of North Dakota, have been named recipients of the President's award for the most significant paper published in the Association *Bulletin* in 1947, by authors under 35 years of age. The title of the paper was "Devonian System in Central and Northwestern Montana."

President CARROLL E. DOBBIN completed his presidential visits to the affiliated societies in April. He attended the luncheon of the North Texas Geological Society at Wichita Falls on April 7; he addressed the Ardmore Geological Society at Ardmore, Oklahoma, on the same day; attended the luncheon meeting of the Oklahoma City Geological Society on April 8; and the luncheon of the Tulsa Geological Society on April 9, returning to Denver, Colorado, on April 10.

E. H. MCCOLLOUGH, vice-president in charge of Pacific Coast and Canadian operations for the Amerada Petroleum Corporation since 1934, has been appointed vice-president in charge of all operations, succeeding the late Allmand F. Blow.

DOLPHE E. SIMIC, division geologist for the Bay Petroleum Corporation and the Chalmette Petroleum Corporation in North Texas, has been appointed chief geologist and exploration manager.

N. P. ISENBERGER, director of foreign exploration for the Phillips Petroleum Company, Bartlesville, Oklahoma, has been elected vice-president in charge of geological and exploration activities abroad for the American Independent Oil Company.

Papers that have been read before the Oklahoma City Geological Society during luncheon meetings are the following: R. M. SWESNIK, of the Anderson-Prichard Oil Company, and ROBERT M. WHEELER, consultant, on February 12, gave a résumé of their joint paper entitled "Stratigraphic Convergence Problems in Oil Finding"; RICHARD P. SWIRCZYNSKI, of the Sohio Petroleum Company, presented a paper on March 25 entitled "Geology of the Northwest Sulphur Pool."

GEORGE L. GOODIN is no longer with the Ohio Oil Company, but is consultant with Petroleum Information, Inc., Continental Oil Building, Denver, Colorado.

TOM E. FOLSOM is with the Honolulu Oil Corporation, Los Angeles, California.

JONATHAN DOUGLAS TURNER, formerly with the Carter Oil Company, is a consultant at Evansville, Indiana.

BETTY JEANNE WILKES, recently in the employ of the Humble Oil and Refining Company is with the Permian Basin Sample Laboratory, Midland, Texas.

PAUL M. JAMESON has resigned from the geological department of the Humble Oil and Refining Company to become a consulting geologist. His address is Box 1884, Tulsa, Oklahoma.

HERBERT C. W. VON EIFF, formerly with the Salt Dome Oil Corporation, has joined the Woodley Petroleum Company, Houston, Texas.

The Geological Forum of the Pacific Section of the Association presented the following program at Los Angeles, California, March 15: "The Recent Discovery at Bacon Hills," by L. S. CHAMBERS, chief geologist, Seaboard Oil Company; "The New Discovery in the Cuyama Valley," by TED BEAR, consultant; and "Recent Exploration Developments in the Salinas Valley," by J. E. KILKENNY, chief geologist, Chanslor-Canfield-Midway Oil Company.

JAMES CLARK TEMPLETON, of the Geophysical Prospecting Company, Ltd., may be addressed at 25 Paines Lane, Pinner, Middlesex, England.

R. J. HUGHES completed his geological studies and received the Master's degree in geology at the University of Texas in January. He is doing geological research for Exploration Surveys, Inc., Dallas, Texas.

LOUIS H. MICHAELSON has resigned from the Skelly Oil Company to enter the employ of the Texas Gulf Producing Company, Midland, Texas.

DORSEY HAGER has opened a field office at Holbrook, Arizona. He still maintains the Centralia, Illinois, address: Box 374.

A. B. ROWLEY and J. W. KISLING, spoke about their recent work in Ethiopia, at the luncheon meeting of the Tulsa Geological Society, March 12.

R. B. DOWNING, Oklahoma City, has been appointed Mid-Continent division manager of the Lane-Wells Company, following the resignation of R. B. McCullar from that position.

ROBERT D. MCCLUER is associated with DILWORTH HAGER, 932 Liberty Bank Building, Dallas, Texas.

A. B. MCCOLLUM is an independent geologist associated with the Pan American Geophysical Company, Staley Building, Wichita Falls, Texas.

THE NATIONAL RESEARCH COUNCIL COMMITTEE ON GEOPHYSICS, ADVISORY TO
OFFICE OF NAVAL RESEARCH

Acting upon a request from Admiral Paul F. Lee, chief of Naval Research, the National Research Council has appointed a committee of active scientific investigators to advise the Geophysics Branch of the Office of Naval Research regarding scientific and related aspects of their research programs. The committee is as follows: WALTER H. NEWHOUSE (chairman), HARRY H. HESS (vice-chairman), ROLAND F. BEERS, MAURICE EWING, ELLIS A. JOHNSON, LESTER E. KLIMM, WILLIAM C. KRUMBEIN, WILLIAM W. RUBEX, and J. FRANK SCHAIRER.

R. C. GIBBS, chairman of the Division of Mathematical and Physical Sciences of the N.R.C., acts as administrative adviser to the committee, in collaboration with ARTHUR BEVAN, chairman of the Division of Geology and Geography.

The committee held its first meeting on January 7 and 8, 1948, in Washington, D. C. As stated by ROGER REVELLE, head of the Geophysics Branch of the Office of Naval Research, that branch is charged with the responsibility within the Navy Department of sponsoring basic research in appropriate fields of earth sciences through financial and other support of worthy projects. Functioning within this general framework of responsibility the committee will, for the present, restrict its consideration to research problems dealing with the crust of the earth and the properties of the earth as a whole.

Since it is part of the policy of the O.M.R. to sponsor research in fields not adequately covered by other agencies, the Geophysics Branch, with the committee's concurrence, has established the following objectives for research within the fields covered by the committee.

1. To foster, in cooperation with other agencies, geological, geographical, and geophysical explorations of little known areas of the earth such as the islands of the Western Pacific and the Arctic and Antarctic. Such exploration may include all aspects of the natural environment and problems of human and economic geography and ethnography as well as the more limited objectives implied in the terms geology and geophysics.
2. To conduct laboratory and field studies leading to a greater understanding of the properties and processes existing in the outer hundred kilometers of the earth's crust.
3. To develop instruments and techniques for determination of the earth's properties; for example, universal airborne magnetometer equipment.

For further details consult the Office of Naval Research, Navy Department, Washington 25, D. C., or the National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

MISSISSIPPI GEOLOGICAL SOCIETY FIELD TRIP, JUNE 18-20

The Mississippi Geological Society will hold its sixth field trip, June 18-20.

The trip will begin at Vicksburg, Mississippi, Friday, June 18 at 7:00 A.M. After study and sampling of outcrops in that vicinity the trip will continue eastward to Meridian,

Mississippi, where papers will be presented and discussion held that evening. The next two days will cover study of outcrops of sediments ranging in age from the Cockfield through the Catahoula formations.

We are cordially inviting all geologists on this field trip. Reservations should be made individually with W. R. Asher, assistant manager, Vicksburg Hotel, Vicksburg, Mississippi, for the night of June 17 and with J. A. Wilson, manager, Lamar Hotel, Meridian, Mississippi, for the nights of June 18 and 19.

PAUL THOMAS and E. T. MONSOUR
Co-chairmen, Field Trip Committee

GEORGE ELMER ABERNATHY, of the Kansas Geological Survey, at Pittsburg, Kansas, died on February 6, 1948.

W. HEGWEIN has left The Hague. He may be addressed in care of the Caribbean Petroleum Corporation, Maracaibo, Venezuela.

HOMER E. ROBERTS has returned to the United States from service with the Caribbean Petroleum Corporation. He is with the Petty Geophysical Company, Box 2061, San Antonio, Texas.

DEAN F. METTS has left the Humble Oil and Refining Company to become chief geologist for the Chicago Corporation's oil and gas division at Corpus Christi, Texas.

HUGH D. MISER, staff geologist, United States Geological Survey, spoke on "Some Notes on Geology and Geologists, 1907-1947," at the meeting of the Tulsa Geological Society, April 19.

JAMES D. McLEAN, JR., research geologist, specializing in micropaleontology and stratigraphy, is situated at 218 King Street, Alexandria, Virginia.

CHANNING B. SCHWARTZ, formerly assistant division geologist for the Carter Oil Company, has been made vice-president of the Cook Drilling Company, Fort Worth, Texas.

The Geological Forum of the Pacific Section of the Association presented the following program, at Los Angeles, California, on April 19: "Recent Developments at Montalvo, Ventura County," by KARL ARLETH, Standard Oil Company; "Race Track Hill Oil Field," by FRED E. VANDENBERG, Kern Oil Company, Ltd.; and "Reflection Seismograph Exploration in Pacific Coastal Waters," by MAYNARD HARDING, United Geophysical Company.

The April issue of the *Slide Rule*, official publication of the Houston Engineers Club, edited by E. E. ROSAIRE, of Subterrex, features MICHEL T. HALBOUTY, consulting geologist of Houston, and contains an article, "Species of Government," by L. W. BLAU, geophysicist with the Humble Oil and Refining Company.

SHERMAN A. WENGERD, assistant professor of geology at the University of New Mexico, has been awarded a Faculty Senate Research Grant to complete the study of the lithogenic history of the Viola limestone in the Arbuckle geosyncline. The study was begun as a doctoral thesis in 1940 and the results are to be published in the *Bulletin* of the American Association of Petroleum Geologists.

H. FOSTER BAIN died at Manila, Philippine Islands, March 9. He was well known in earlier years as director of the United States Bureau of Mines and as secretary of the American Institute of Mining and Metallurgical Engineers.

LUTHER H. WHITE, on the geological staff of the Sinclair Prairie Oil Company, Fort Worth Office, is at Midland, Texas.

JOHN D. HALE has left the Superior Oil Company, Los Angeles. He is employed by the Seaboard Oil Company of Delaware, Bakersfield, California.

ERNEST R. LILLEY has been appointed general manager of the Tulsa office of the Great Lakes Carbon Corporation.

W. ARMSTRONG PRICE read his paper on "Pimple Mounds," before the Houston Geological Society, Houston, Texas, April 12. He discussed the origin of the mounds by pocket gophers, their correlation, distribution, age, and significance in Quaternary geology.

ROBERT L. ALKIRE is with the Geological Survey of Ohio, Orton Hall, Ohio State University, Columbus, Ohio.

CECIL HAGEN, consulting geologist, Houston, Texas, is making a trip to several countries in South America. He plans to be gone approximately two months and will do geological work, mainly in Ecuador.

SHREVEPORT GEOLOGICAL SOCIETY FIELD TRIP, MAY 22-23

The members and friends of the Shreveport Geological Society are invited to attend a Field Trip to examine the Paleozoic formations of the Ouachita Mountains and the Magnet Cove area, Arkansas.

TIME: May 22 and 23, 1948 (registration May 21)

PLACE: Headquarters, DeSoto Hotel, Hot Springs, Arkansas

CONFERENCE LEADERS: Hugh Miser (U.S.G.S.), H. B. Foxhall and D. F. Holbrook (Arkansas G. S.), Norman F. Williams

LOCALITIES: Ouachita Mountains (Pennsylvanian-Cambrian). Magnet Cove (Igneous intrusion and barite quarry).

TRANSPORTATION: Buses will be used because of road conditions and to speed progress.

REGISTRATION: Friday afternoon and evening May 21 at DeSoto Hotel, Hot Springs.

REGISTRATION FEE: Will cover (1) guide book, (2) bus transportation, and (3) buffet supper, Saturday night.

HOTEL ACCOMMODATIONS: Rooms in DeSoto Hotel: \$3.00-\$4.00.

GAYLE SCOTT, professor of geology at the Texas Christian University, Fort Worth, Texas, died on April 25, at the age of 53 years. Excepting 2 years while in military service in World War I, he had been a teacher in the University continuously since graduating there in 1917. He was editor of the A.A.P.G. *Bulletin* in 1944, 1945, and 1946. His wife, Mary Beth Scott, survives him. The home address is 2916 Princeton Street, Fort Worth.

ALFRED C. LANE, of Tufts College, Massachusetts, died on April 16, aged 65 years.

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Originally published as Part II of the August, 1946, Bulletin

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Frontier Refining Company
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Evening dinner (6:30) and technical program
(8:00) first Tuesday each month or by announce-
ment.

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Vice-President - - - - - Don W. Payne
Sinclair Prairie Oil Company
Secretary-Treasurer - - - - - Shirley E. Lenderman
Stanolind Oil and Gas Company
Regular Meetings: 7:30 P.M., Geological Room,
University of Wichita, first Tuesday of each month.
Noon luncheons, first and third Monday of each
month at Wolf's Cafeteria. The Society sponsors
the Kansas Well Log Bureau, 412 Union National
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reau, 137 North Topeka. Visiting geologists and
friends welcome.

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General Petroleum Corp., 108 W. 2d St.
Los Angeles 12, California
Monthly meetings. Visiting geologists are welcome.

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and friends are welcome.

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Continental Oil Company, 606 Division St.
Evansville, Indiana
Secretary-Treasurer - - - - - E. J. Combs
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Meetings will be announced.

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301 Pere Marquette Bldg.
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Secretary-Treasurer - - - - - D. N. Rockwood
Union Producing Company, Box 1628
Meets the first Monday of every month, October-
May, inclusive, 7:30 P.M., St. Charles Hotel.
Special meetings by announcement. Visiting geol-
ogists cordially invited.

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Union Oil Company of California
Ricou-Brewster Building
Secretary-Treasurer - - - - Richard T. Chapman
Stanolind Oil and Gas Company, Box 1092

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

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Amerada Petroleum Corporation
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Treasurer - - - - - Philip R. Allin
Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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GEOLOGICAL SOCIETY

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Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Business Manager - - - - - Jack Mortenson
Sohio Petroleum Company, Mt. Pleasant
Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

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GEOLOGICAL SOCIETY
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Vice-President - - - - - R. D. Sprague
Sinclair Wyoming Oil Company
Secretary-Treasurer - - - - Carl F. Grubb
Superior Oil Company
Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

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The California Company, Box 153
Secretary-Treasurer - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

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OKLAHOMA CITY, OKLAHOMA

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Vice-President - - - - - Ben F. Baldwin
Stanolind Oil and Gas Company
Secretary - - - - - L. R. Wilson
Carter Oil Company
1300 Apco Tower
Treasurer - - - - - R. W. Edmund
Globe Oil and Refining Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Lunches: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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SHAWNEE, OKLAHOMA

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Atlantic Refining Company, Box 169
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Vice-President - - - - - Fred J. Smith
Sinclair Prairie Oil Company
Box 991, Seminole
Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Sinclair Prairie Oil Company, Box 521
Secretary-Treasurer - - - - V. L. Frost
Ohio Oil Company, Thompson Building
Editor - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Student Union or Tyrrell Hall. Luncheon: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

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Independent, Box 1675

Secretary - - - - - David K. Kirk
Gulf Research and Development Co., Box 2038
Treasurer - - - - - C. H. Feldmiller
111 Haldane Avenue, Pittsburgh 5

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

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Consulting Geologist

Vice-President - - - - - J. R. Day
Pan American Production Company

Secretary-Treasurer - - - - - Riley G. Maxwell
Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:00 P.M., Wooten Hotel.

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1400 Continental Building

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Secretary-Treasurer - - - - - H. V. Tygrett
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Executive Committee - - - - - Barney Fisher
Comanche Corporation
406 Continental Building

Meetings: Monthly luncheons and night meetings by announcement.

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Stanolind Oil and Gas Company
Box 1410

Secretary-Treasurer - - - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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CORPUS CHRISTI, TEXAS

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Union Oil Company of California

Secretary-Treasurer - - - - - H. C. Cooke
c/o O. G. McClain, 224 Wilson Building

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

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Vice-President - - - - - P. S. Schoeneck
Atlantic Refining Company
205 Manztel Building

Secretary-Treasurer - - - - - J. C. Price
Magnolia Petroleum Company
Box 780

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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Secretary - - - - - Hershail C. Ferguson
Consultant, 1208 Esperson Building

Treasurer - - - - - Eugene L. Earl
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Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

TEXAS

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Anderson-Prichard Oil Corporation

Secretary-Treasurer - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010, Radio Bldg.

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Vice-President - - - - - Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building

Secretary-Treasurer - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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Editor - - - - - R. Douglas Rogers
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Union Trust Building, Parkersburg, West Virginia

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Daniel Boone Hotel.

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Secretary-Treasurer - - - Fred S. Alexander
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Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Treasurer - - - - - Jane M. Johnson
Permian Basin Sample Laboratory, Box 1653

Meetings will be announced.

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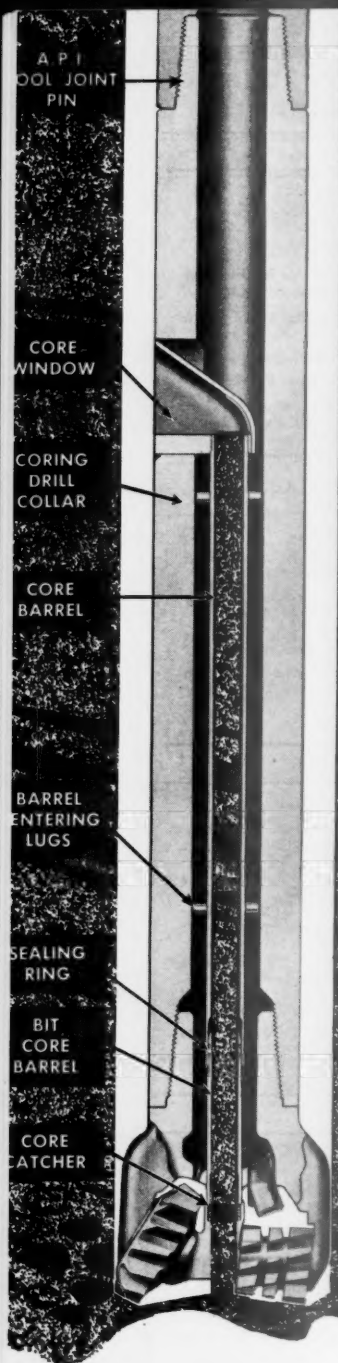
A symposium conducted by the Research Committee of The American Association of Petroleum Geologists, A. I. Levorsen, chairman. Papers read at the Twenty-sixth Annual Meeting of the Association, at Houston, Texas, April 1, 1941, and reprinted from the Association *Bulletin*, August, 1941.

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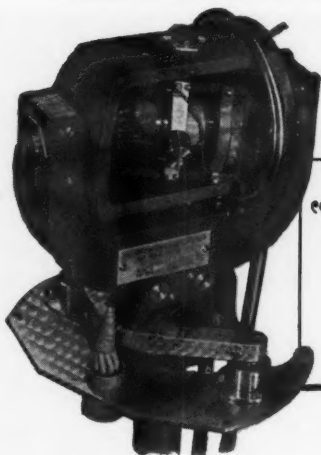
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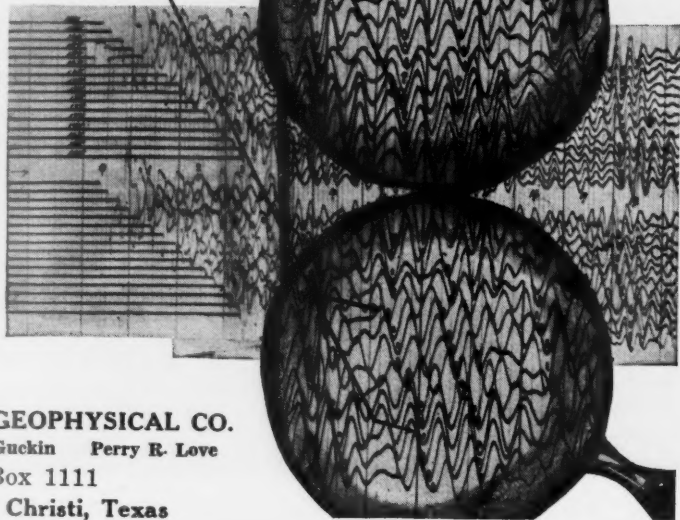
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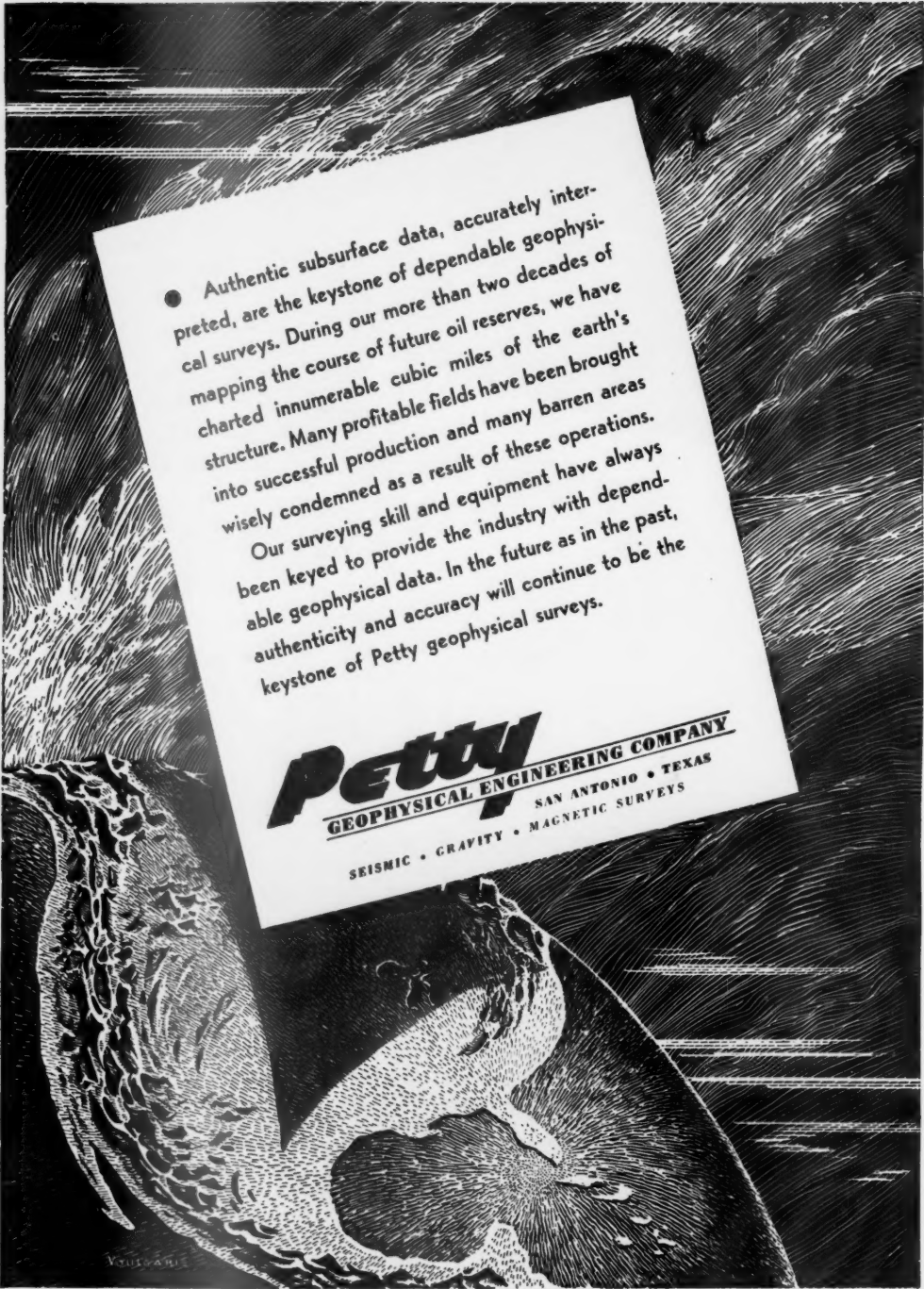
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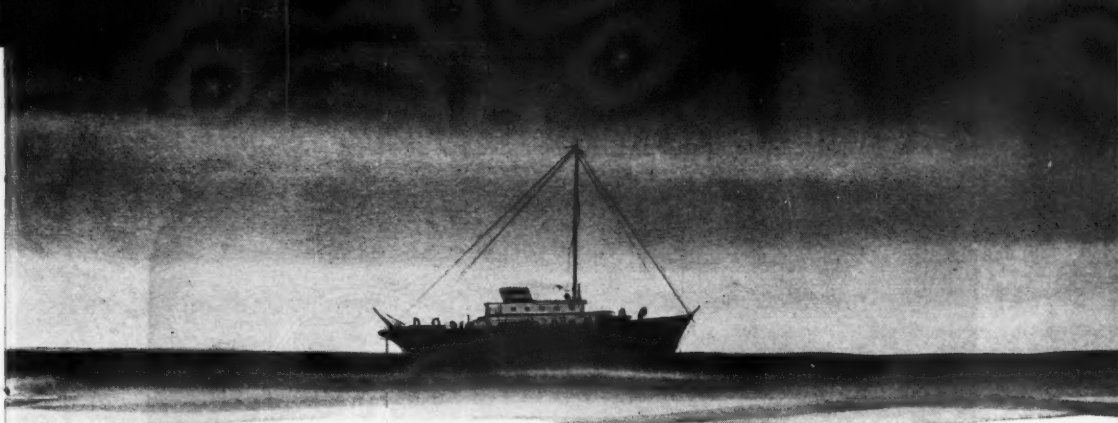
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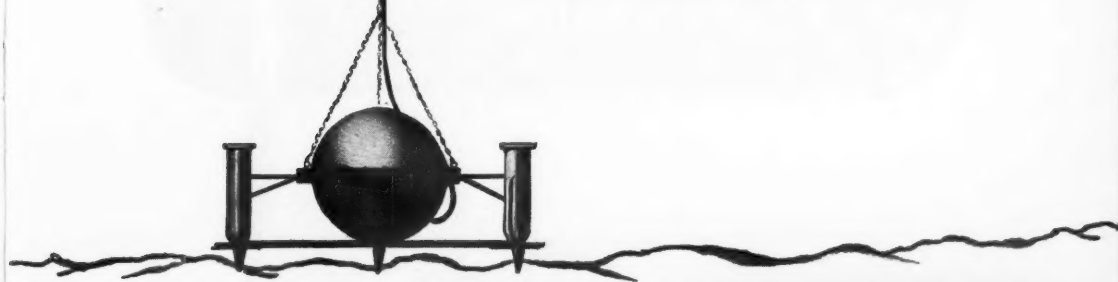


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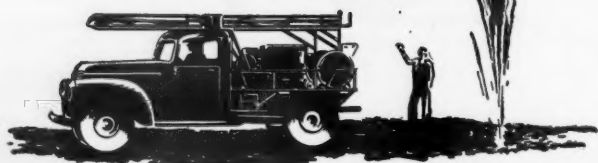
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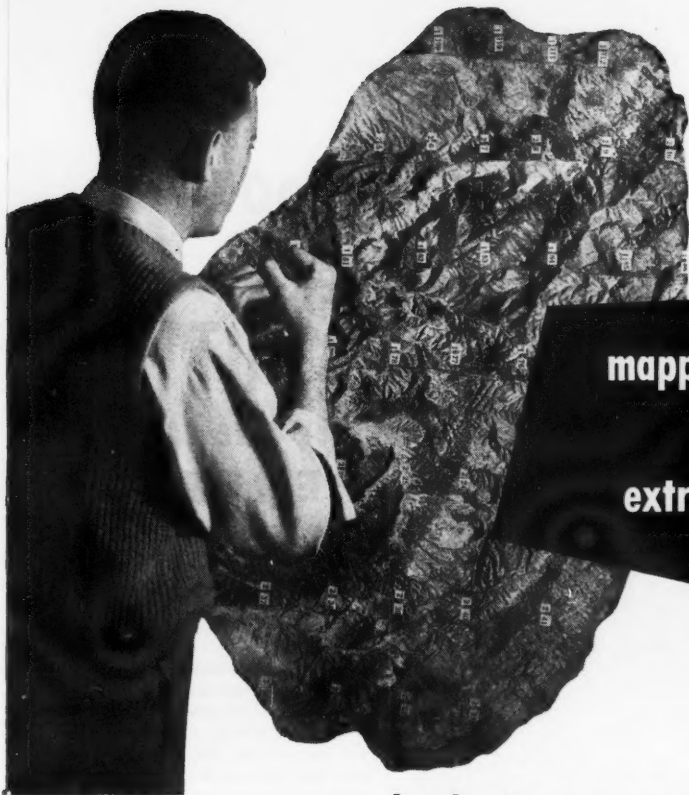
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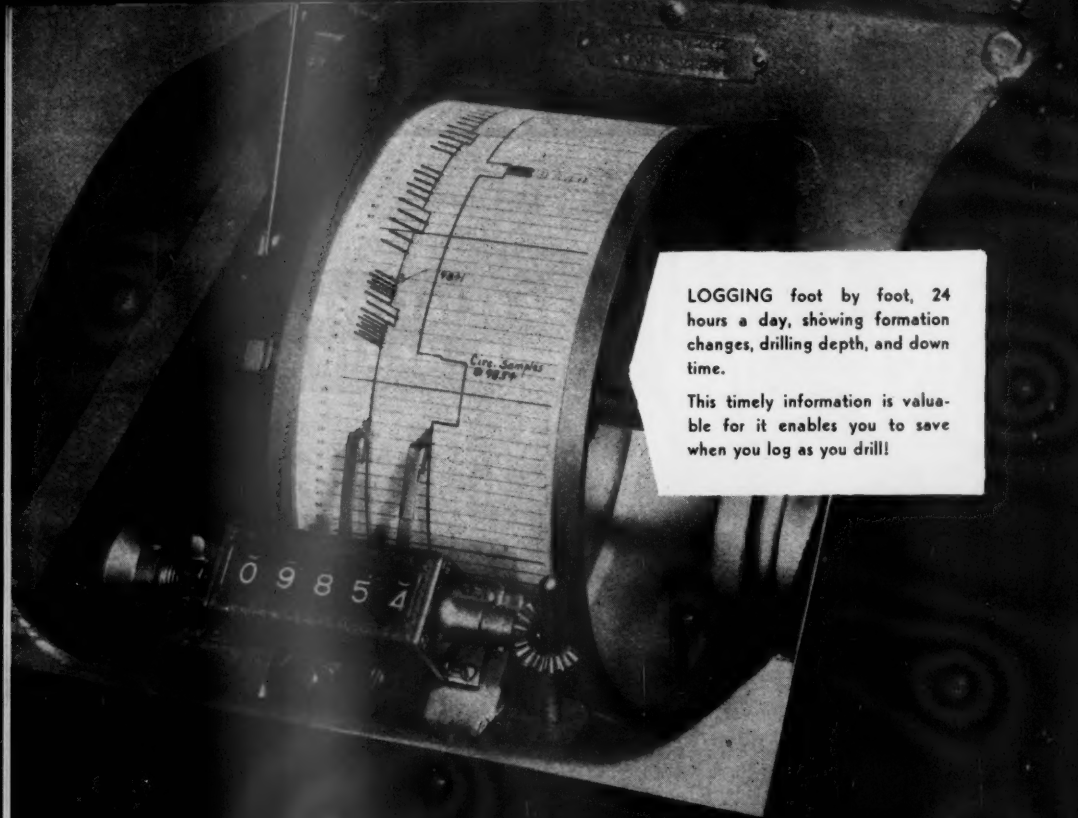


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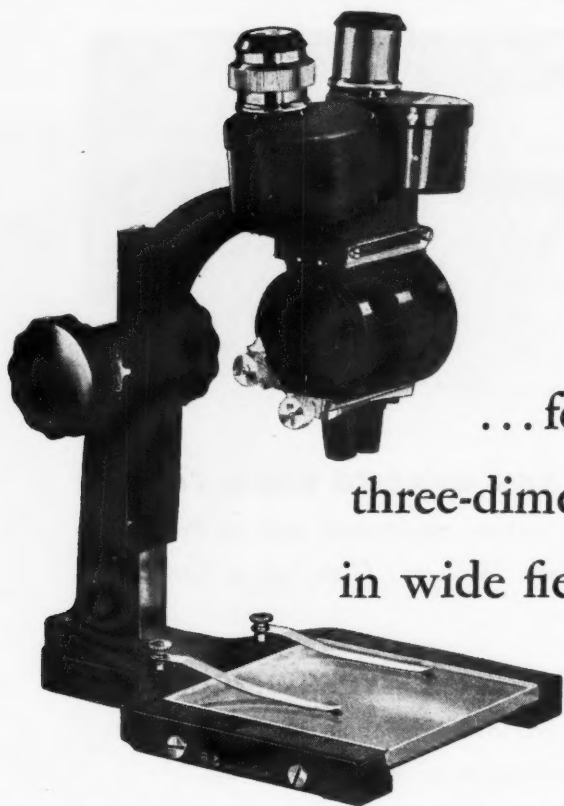
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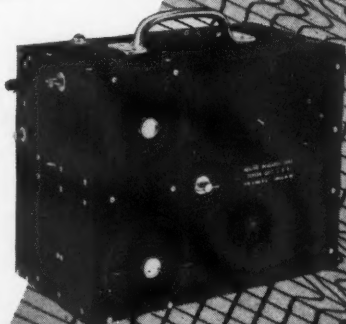
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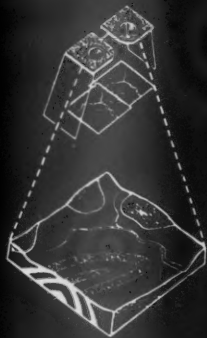
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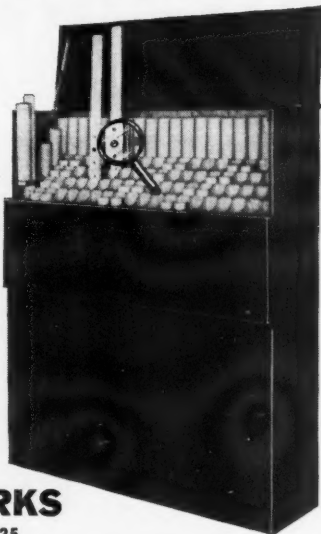
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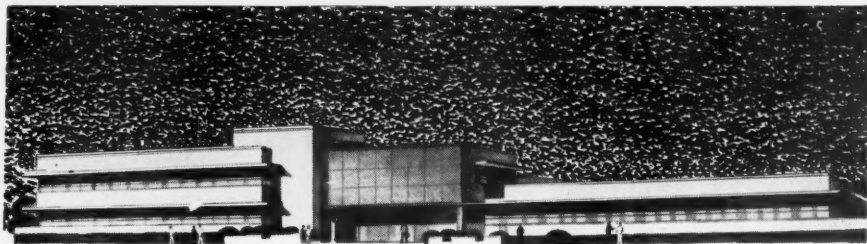
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